COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

January 1959

Night view of the Carbon Steam Electric Plant,
Utah Power & Light Co., near Helper, Utah.

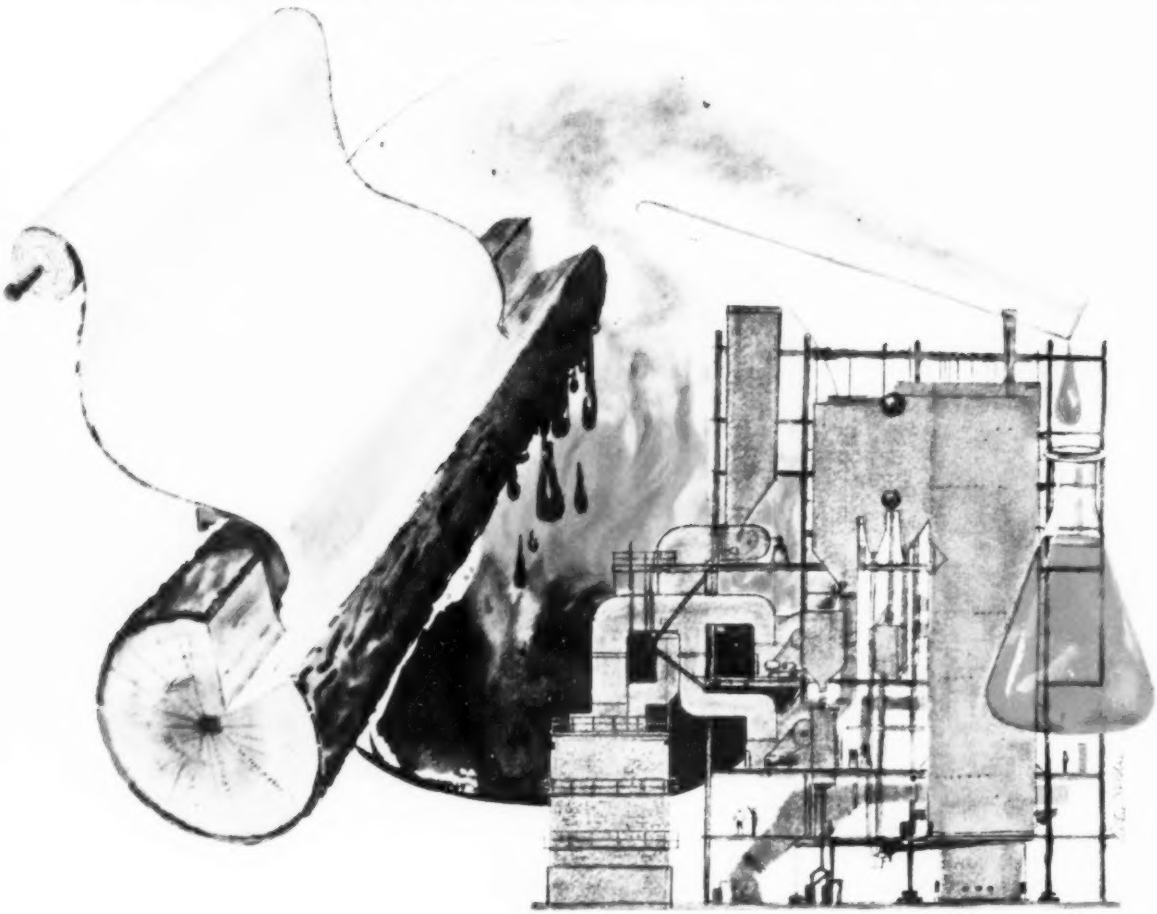
Mechanism of Combustion

Power Plant Clinic

Nineteenth Annual Water Conference

ASME Annual Meeting—II

"CREATIVE ENGINEERING" REAPS A CHEMICAL HARVEST . . . BUILDS PULP-AND-PAPER PROFITS



World's largest chemical recovery unit achieves unprecedented economies in the pulp and paper industry

Chemical recovery is basic to the multi-billion-dollar pulp-and-paper industry. Valuable chemicals are salvaged from "black liquor," a residue of pulp manufacture. And the modern recovery process also produces large quantities of by-product steam.

Just a few years ago, the industry believed that recovery units had reached maximum size, with capacities (black liquor dry solids) of about 1,000,000 pounds per day. C-E engineers, aware that larger installations would mean lower investment and operating costs per unit of capacity, developed half a dozen major innovations in quick succession—and broke through the size barrier.

Twenty-five units of more than 1,000,000-pounds capacity have since been purchased from C-E by leading producers. The largest of these—a 2,000,000-pound unit—has now been in service for more than a year. Despite their high initial costs, such units usually pay for themselves in about two years.

This concern with a specific industry's capital problems—and deep involvement with that industry's technology—is characteristic of the C-E approach.

"CREATIVE ENGINEERING" is the foundation on which Combustion's leadership rests. The products which bear the C-E mark of leadership include:

all types of steam generating, fuel burning and related equipment · nuclear power systems · paper mill equipment · pulverizers · flash drying systems · pressure vessels · soil pipe

COMBUSTION ENGINEERING

Combustion Engineering Building, 200 Madison Avenue, New York 16, N. Y.

C-193

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 30 **No. 7**

January 1959

Feature Articles

The Mechanism of Combustion of Pulverized Coal .... *by P. O. Rosin* 28

Steam Power Plant Clinic-V .... *by Igor J. Karassik* 39

Nineteenth Annual Water Conference 43

ASME Annual Meeting Highlights—II 49

Abstracts From The Technical Press—Abroad and Domestic 59

Editorials

Man's Conflict With Technical Progress 27

Departments

Advertising Index 66, 67

COMBUSTION publishes its annual index in the June issue and is indexed regularly by Engineering Index, Inc. and also in the Applied Science & Technology Index.

The magazine is now reproduced and distributed to libraries on microfilm by University Microfilms of Ann Arbor, Michigan.

Published monthly by COMBUSTION PUBLISHING COMPANY, INC., 200 Madison Ave., New York 16
A SUBSIDIARY OF COMBUSTION ENGINEERING, INC.
Joseph V. Santry, Pres.; Charles McDonough, Vice-Pres.; Otto Strauss, Treas.; Thomas A. Ennis, Secy.
COMBUSTION is sent gratis to engineers in the U. S. A. in charge of steam plants from 500 rated boiler horsepower up; and to consulting engineers in this field. To others the subscription rate, including postage, is $4 in the United States, $5.50 in Canada, and $8 in Latin America and other countries. Single copies: Domestic, 40 cents, Foreign, 60 cents plus postage. Publication Office, Easton, Pa. Issued the middle of the month of publication.
Acceptance under Section 34.64, P.L. & R., authorized by United States Post Office.

BPA

Printed in U. S. A.

Hall Industrial Water Report

VOLUME 7 | **JANUARY 1959** | **NUMBER 1**

Let's Get This Clear

Day after day new products are being developed to improve the clarification of water. The standard coagulants, aluminum and iron sulfates, have long been supplemented with aids like clay and magnesium oxide. Some 20 years ago Baylis developed activated silica. But today new materials to assist clarification with the standard coagulants are coming along faster and faster. They are designed to improve removal of color, bacteria and suspended material from potable and industrial water, to cut costs by reducing coagulant consumption, to assist in removal of deleterious materials from waste water and to assure optimum operation of clarifiers and filters.

Hall Laboratories research and development continually provides improved coagulant aids, field tested for performance. Furthermore, Hall engineers know clarification equipment and processes. They are ready to help you improve clarification or reduce water treatment cost.

Feeding Ferric Sulfate

Ferric sulfate is a commonly used coagulant. When fed with a solution feeder, care must be taken to get the chemical completely into solution. Otherwise, undissolved material will cause trouble in the feeding equipment and effectiveness will be lost.

Each pound of ferric sulfate liberates about 260 BTU when it goes into solution. The resulting solution temperature increase has an important effect on rate of solution. If tap water temperature is too low, or if the ratio of water to ferric sulfate is too high, there will be troublesome undissolved material. Furthermore, final solution temperature should be 90° 100° F.

The practical trick for easy handling is careful adjustment of the water-to-chemical ratio. If water temperature is 68° F., dissolution of ferric sulfate will be complete in 18 minutes and final solution temperature will be about 98° F., if the ratio of water to solid ferric sulfate by weight is five. If water temperature is only 47° F., the solution rate and final temperature will remain the same, provided the ratio of water to chemical is cut to three. These examples may be used as a guide; obtain complete dissolving information from the manufacturer of the material used.

Water Color Problem

An Eastern woolen mill is located downstream from other woolen mills, a steel mill and a sewage plant. Needless to say, the river water is badly contaminated with organic coloring matter, suspended matter and detergents during summer droughts and extremely cold weather. Clarification has been difficult. Even with heavily increased alum dosages color removal was poor. This was a costly situation because it frequently necessitated reprocessing of the delicate pastel shades which are a specialty of this mill.

More than two years ago Hall Laboratories introduced the plant to coagulant aids. After laboratory jar tests were carried out to determine the type of aid best suited to this particular case, the plant adopted the use of a Hagan aid during periods of high color. Not only have floc formation, sedimentation and color removal been greatly improved, but alum dosage has been reduced by 25%. The plant operators say they feel sure they would have had to suspend operations during the 1957 drought if they had not been using the Hagan coagulant aid.

No Clarifier Needed

A growing Southern textile plant was forced to curtail operations because water requirements exceeded the total capacity of the wells. Further expansion was anticipated. The additional water required would have to come from a surface supply.

Faced with the installation of expensive clarification equipment and costly chemical treatment to make the water suitable for process work, the plant called on Hall Laboratories to study the problem. Hall engineer R. E. Elliott carried out the survey and came up with a money-saving answer. He found that a lot of water could be saved by re-using cooling water from closed heat exchangers, by repairing overflow mechanisms and by using untreated surface water for non-critical operations. No treatment of surface water would be necessary and enough good quality well water would be saved to permit *doubling* current operations.

Potential Trouble

When Hall engineer Peter Benes began service work at a Southern chemical plant he found a clay-like deposit accumulating in the sodium cycle units of the split-stream softeners. Because of previous bad experiences with aluminum in boiler water, Benes became alarmed when analysis showed the deposit to contain considerable aluminum.

Further analytical work traced the aluminum to the clarified and filtered makeup water. Clarification was accomplished with aluminum sulfate; but operation and pH value were such that there should have been very little aluminum in the filtered water. Benes kept digging. He found that soda ash, used to adjust upward the pH of the clarified water, was being added ahead of the filters. This resulted in dissolution of some of the small amount of suspended aluminum hydroxide floc passing to the filters.

Immediate change was made to feed the soda ash after the filters. Aluminum concentration of the filtered water dropped from 0.15 ppm to 0.05 ppm and the problem was solved.

Industrial Water Problems Require Special Handling

There are no "stock answers" to industrial water problems. For information on how the Hall System can help you solve your particular water problems, write, wire or call address below.

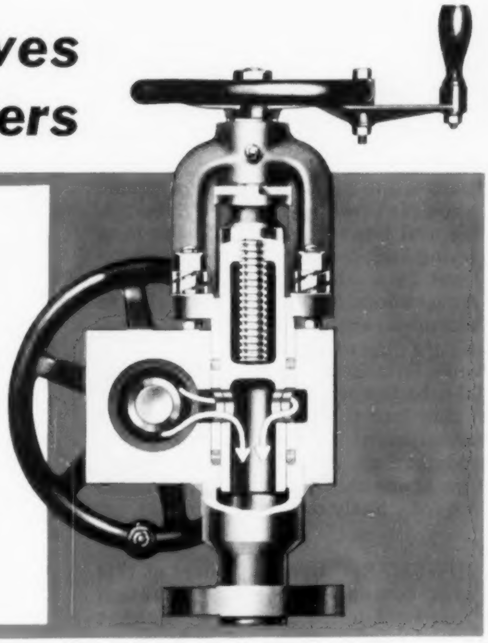
Water is your industry's most important raw material. Use it wisely.

HALL LABORATORIES
DIVISION OF HAGAN CHEMICALS & CONTROLS, INC.
HAGAN BUILDING, PITTSBURGH [illegible], PA.
In Canada: Hagan Corporation (Canada) Limited, [illegible]

Hall Laboratories—Consultants on Procurement, Treatment, Use and Disposal of Industrial Water

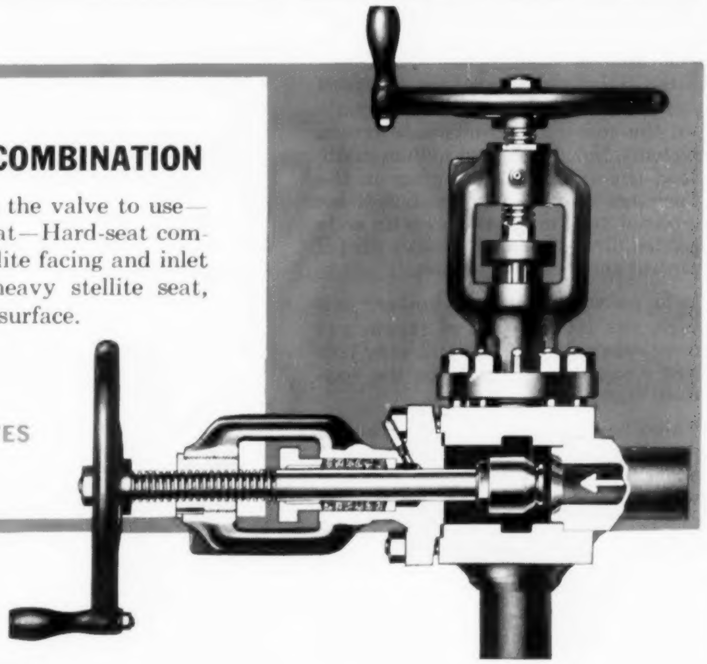
UNIT TANDEM

rugged blow-off valves for high pressure boilers



HARD-SEAT—SEATLESS COMBINATION

■ For boilers up to 1500 psi, this Yarway Unit Tandem Blow-Off Valve offers the maximum in dependable service. A one-piece forged steel block serves as the common body for the Yarway Stellite Hard-seat blowing valve and the Yarway Seatless sealing valve. All interconnecting flanges, bolts and gaskets are eliminated. The Unit Tandem at right is sectioned through Seatless Valve to show balanced sliding plunger in open position and free flow.



HARD-SEAT—HARD-SEAT COMBINATION

■ For boilers to 2500 psi, this is the valve to use—Yarway's Unit Tandem Hard-seat—Hard-seat combination. Disc has welded-in stellite facing and inlet nozzle has integral welded-in heavy stellite seat, providing smooth, hard-wearing surface.

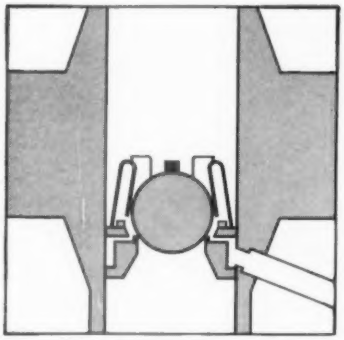
OVER 4 OUT OF 5
HIGH PRESSURE PLANTS
USE YARWAY BLOW-OFF VALVES

Write for Yarway Catalog B-434

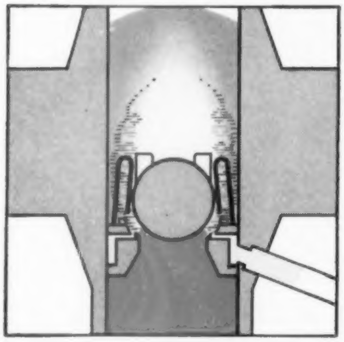
YARNALL-WARING COMPANY
100 Mermaid Ave., Philadelphia 18, Pa.
BRANCH OFFICES IN PRINCIPAL CITIES

YARWAY BLOW-OFF VALVES

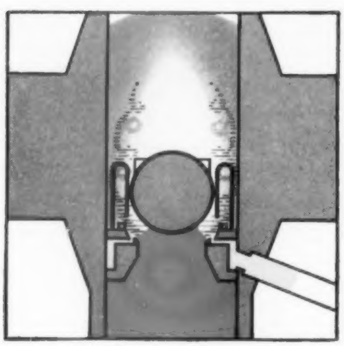
SIMPLE PRINCIPLE OF OPERATION



No load: Ball has seated itself on the ring. There is no flow of steam—no flow of cooling water.

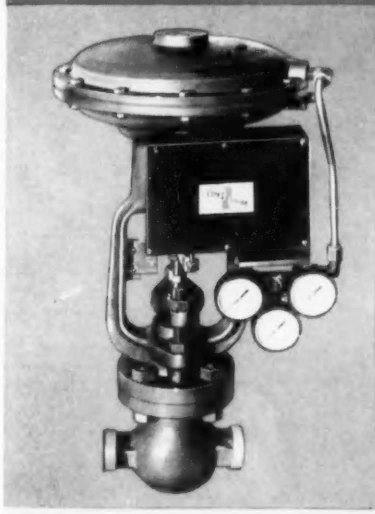


Light load: Ball opens orifice slightly. Cooling water is instantly and intimately mixed with steam.



Full load: Orifice fully opened. There is the same pressure drop and high turbulence at all loads over the full range.

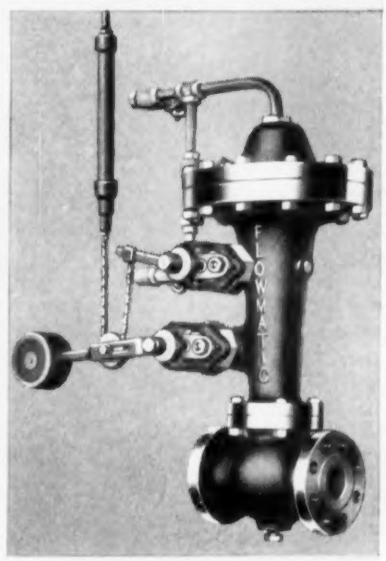
C-V NEWS NOTES



A Type CV-D Pressure reducing valve is used at Front Street Station to automatically regulate the cooling water supplied from the feed-water-heater.

This Copes-Vulcan diaphragm valve is designed to dependably meet rigid standards of accuracy for pressure, temperature and liquid level control. The Type CV-D may be direct or reverse acting. Rangeability is excellent.

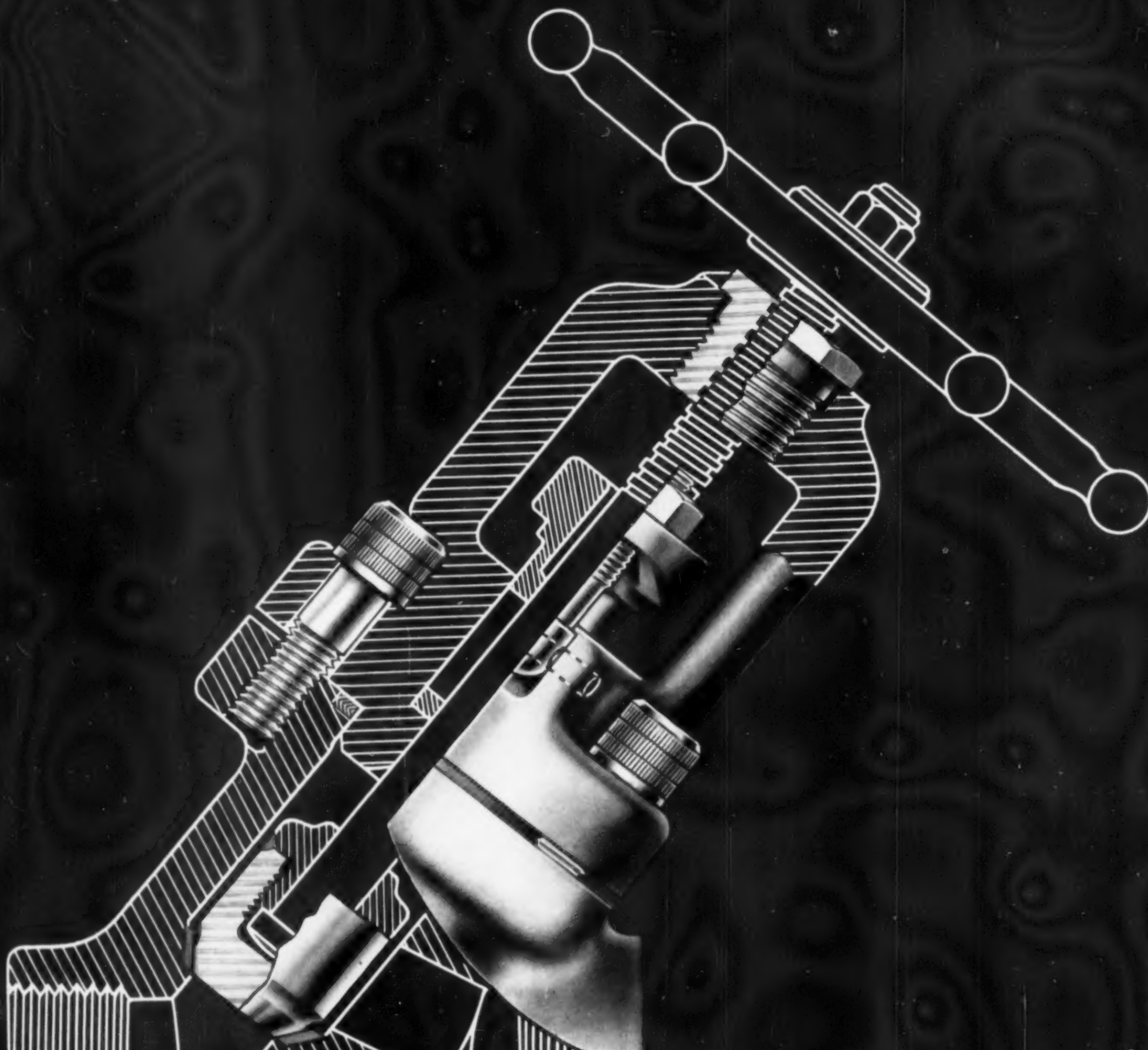
Style and area of valve ports are scientifically selected to meet specified operating conditions. These versatile valves can be applied in sizes up to 12 inches in pressure—standards up to 1500 pounds. For details on Copes-Vulcan valves, write for Bulletin 1027.



For modern feed water control: The Copes Flowmatic, a two-element feed water regulator, is sensitive to the slightest change in steaming rate, and to the most minute fluctuation of boiler water level.

Closer stabilization of boiler water level under all load conditions makes the Copes Flowmatic ideal for the modern utility and industrial boilers subject to rapid, wide fluctuations in steam demands.

With the direct-operated Flowmatic Regulator (shown above) the steam flow element is built integral with the valve bonnet. In regular service outdoors, the Flowmatic Type D-O is unaffected by atmospheric conditions, provides accurate, dependable performance. For further information, write for Bulletin 1003-A.



EDWARD "848" SERIES GLOBE VALVE
(ANGLE TYPE ALSO AVAILABLE)

What's New from Edward Valves

New Products . . . Problems and Solutions. . . Information on Steel Valves from Edward, Long-Time Leader in the Field!

Major Improvements at No Extra Cost Mark
New "848" Series Forged Steel Stop Valves

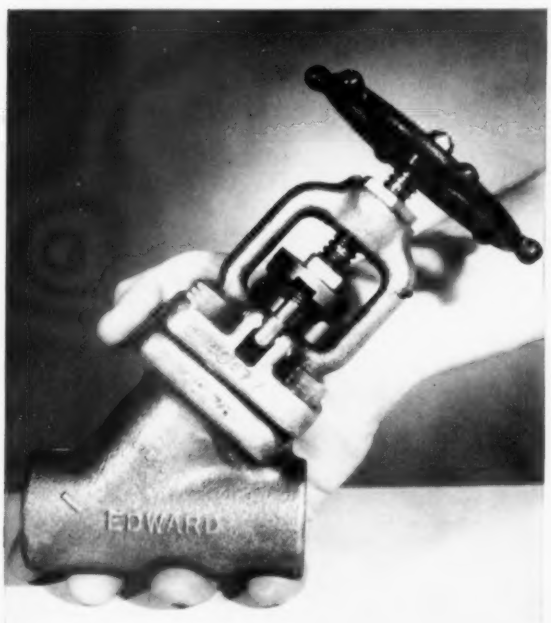
In an industry where any change in design is "news," Edward is proud to introduce a new line of 600-lb forged steel stop valves with so many major design improvements *at no increase in cost.* These Rockwell-built Edward valves are suitable for air, water, oil and other hydrocarbons, anhydrous ammonia and other gases, steam and other non-corrosive fluids.

NEW MATERIALS USED THROUGHOUT

Besides tough drop-forged steel, which is the basis of these valves, Edward introduces such innovations as stainless steel gland bolts, an aluminum-bronze yoke bushing, solid disk of chromium-cobalt-tungsten stainless steel, spiral wound gasket of stainless steel and asbestos, and special alloy cap screws linking body and bonnet.

NEW IMPROVED BODY-BONNET JOINT

Four molybdenum alloy cap screws secure bonnet to valve body. These compact, high-strength cap screws require less space than ordinary nuts and bolts, can be handled with one hand, and deliver maximum compressive force with minimum tightening torque. A new spiral wound gasket, consisting of some 20 turns of stainless steel and asbestos, provides controlled compression not possible with ordinary flat gaskets. Because this spiral wound gasket is free to expand and contract as needed, it "takes up the slack," maintains a leak-proof seal between body and bonnet.



NEW SOLID DISK OF SPECIAL ALLOY

Disk is made of chromium-cobalt-tungsten stainless steel. This new alloy has added resistance to erosion, holds its hardness better under high temperatures than other disk materials. Disk is lock-welded to disk nut, eliminating wobble and chatter—especially important when valve is called upon for throttling duty

INTEGRAL STELLITE SEAT FOR LONG LIFE

Valve seat is Stellite—a harder, longer-wearing material with excellent resistance to corrosion, erosion and temperature. Seat is integrally welded to body.

"848" SERIES ROCKWELL-BUILT EDWARD VALVES are available in 1/4", 3/8", 1/2", 3/4" and 1" sizes. They are rated at 600 psi—at 910F in carbon steel and at 1030F in chrome-molybdenum steel. Globe or angle types, with screwed or welding ends. Write for facts on performance . . . price . . . and delivery. Address *Edward Valves, Inc., 1206 West 145th Street, East Chicago, Indiana.* (Subsidiary of Rockwell Manufacturing Company.) Represented in Canada by Lytle Engineering Specialties, Ltd., 360 Notre Dame St. W., Montreal 1, Quebec.

EDWARD STEEL VALVES

another fine product by

ROCKWELL

Catalog 14 contains full data on the complete Edward line of forged and cast steel valves from 1/4" to 18"; in globe and angle stop, gate, non-return, check, blow-off, stop-check, relief, hydraulic, instrument, gage and special designs; for pressure up to 10,000 lbs; with pressure-seal, bolted, union or welded bonnets, with screwed, welding or flanged ends.

The Valley Camp Coal Company provides a complete combustion engineering service for its customers, actual and prospective.

Meeting with a Valley Camp Representative has been the first step to lowered steam costs for many companies..... *How about yours?*

THE VALLEY CAMP COAL COMPANY

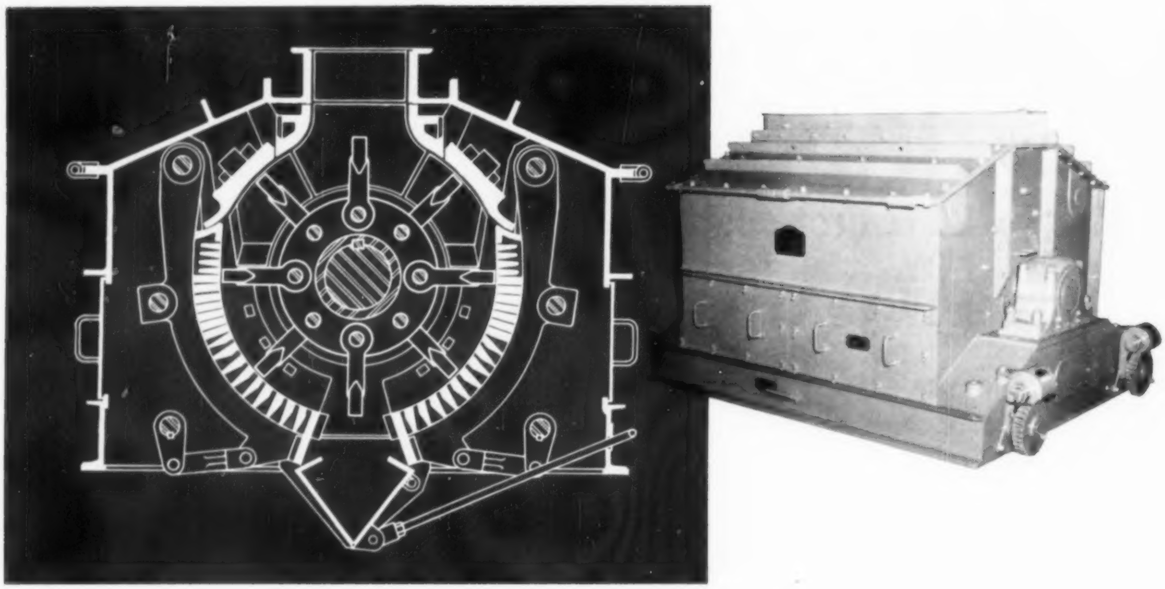
Western Reserve Building • Cleveland 13, Ohio

SUBSIDIARIES —

Great Lakes Coal & Dock Co., Milwaukee, Wis. • Great Lakes Coal & Dock Co., St. Paul, Minn. • Fort William Coal Dock Co., Ltd., Fort William, Ont. • The Valley Camp Coal Co. of Canada Ltd., Toronto, Ont. • Kelley's Creek & Northwestern Railroad Co. • Kelley's Creek Barge Line Inc. • Pennsylvania & West Virginia Supply Corp.

SALES OFFICES —

Philadelphia • Baltimore • Buffalo • Pittsburgh • Wheeling • Cleveland • St. Paul • Cincinnati • New York • Milwaukee • Superior, Wis. • Fort William, Ont. • Toronto, Ont.



Here's how the Pennsylvania Reversible Hammermill will help lower your operating costs

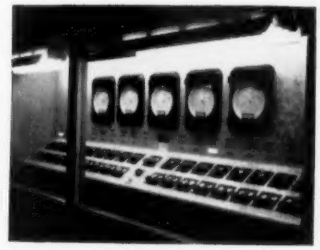
As the coal enters the mill it is precrushed in the upper zone by being struck by the hammers in free air, driven against the breaker blocks, ricocheting and struck by hammers again. Only small lumps enter the lower crushing zone for final reduction before escaping through the cage bars. There's no dragging of hammers through oversize in the lower crushing zone. Thus wasteful fines are held to a minimum along with hammer wear and power requirement. The easily adjusted cages assure you a uniform product for the life of the hammers regardless of variance of the physical properties of the coal. The cage adjustment also permits you to wear the hammers much further, and, due to reversibility of the rotor, there is no manual turning of the hammers. Get the complete story of these crushers. Send for bulletin 1040. Pennsylvania Crusher Division, Bath Iron Works Corporation, West Chester, Penna.

Penn CRUSHER

PE-308

HAGAN NEWSLETTER

Behind the Panel



HOW AUTOMATIC ARE AUTOMATIC CONTROLS?

The answer depends a lot on the reliability factor in the system, and on how well the various control elements are integrated. A great many control systems are designed to operate on full automatic only when the process is within normal operating range. In applications where the process can vary widely, or where operators must be relieved of control supervision during abnormal conditions, true automatic control is desirable. Hagan systems are designed to accomplish this; for example:

OUTDOOR BOILER CONTROL SYSTEM STAYS ON AUTOMATIC DURING GENERATOR TRIP-OUT: a new outdoor utility station in the Southwest experienced a generator trip-out, and in the excitement, the 3-element feed-water control system was left on automatic. Inspection of charts after the difficulty was overcome showed that the feedwater system had maintained proper drum level throughout the two hour shut-down, even though the system went through the complete shut-down, start-up cycle.

SOAKING PITS NEVER OPERATED ON MANUAL CONTROL: on a new installation of two batteries of 3 pits, the heaters are instructed never to operate on manual control. In case of control malfunction, the pits are shut down until the system is repaired. In a year of operation, this policy has resulted in the loss of only four pit hours production time. Pit bottoms have not built up excessively, indicating close control of combustion and absence of ingot washing. (Item A-1)

FIRST SOLID STATE ELECTRONIC BOILER CONTROL SYSTEM

Operational magnetic amplifiers, used as basic control elements in the combustion, feedwater, pump recirculation and steam temperature control systems, will be installed on a new 1,260,000 lb/hr boiler at a Southern utility. The Hagan proposal--for the first solid state electronic boiler control--was selected by the utility in competition with two other electronic systems that did not achieve the reliability inherent in a solid state system. (Item A-2)

ELECTRONIC TEMPERATURE CONTROLLER SENSES 0.000001 VOLT CHANGE

Ultrasensitive, the Hagan PowrAmp Temperature Controller is responsive to thermocouple output fluctuations of one-millionth of a volt Designed for precise temperature control in situations where either the heater or the product temperature can change rapidly, the Controller provides adjustments for proportional band, reset, and rate action. While this is a new instrument, it has already been proven in action. It was selected for the critical job of controlling glass fiber drawing dies operating at 1600F and it is limiting die temperature fluctuation to less than 0.25F. The Controller provides stepless regulation and will handle up to 330 kva through saturable reactors. (Item A-3)

NEW POWRLOG OFFERS LOW-COST TEMPERATURE MEASUREMENT OR CONTROL

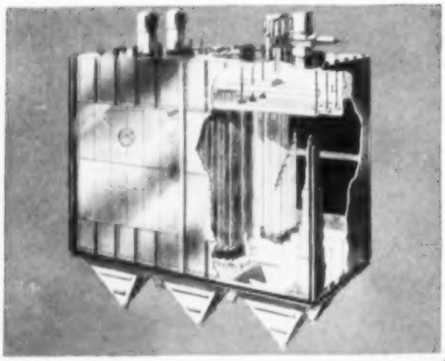
Our systems engineers wanted a rugged, low-cost remote recorder for process measurement in industrial applications. Once we decided that the right way to minimize maintenance was to make use of unitized construction, the acorn we had been asked for rapidly became a full fledged oak. We ended up with an instrument that will measure any function that can be converted into an error voltage, either AC or DC, and then convert these voltages into mechanical movement that may be used for driving a recorder, indicator, integrator, pneumatic transmitter or a controller.

Utilizing a unique amplifier that is adaptable to a wide variety of applications by means of plug-in input boxes, the new HAGAN PowrLog is particularly well suited for the remote measurement and or control of temperature with either thermocouples or resistance bulb thermometers. The components of this versatile instrument have been selected for accuracy and high reliability--result--maintenance has been reduced to a new low. (Item A-4)

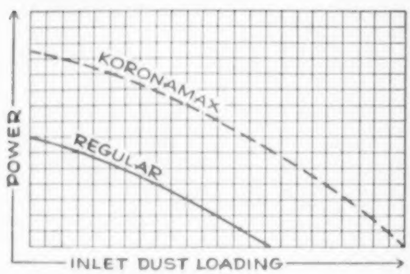
HAGAN CHEMICALS & CONTROLS, INC.
Hagan Building, Room 700, Pittsburgh 30, Pa.

If you would like more information on any of the above items, check the appropriate box below.

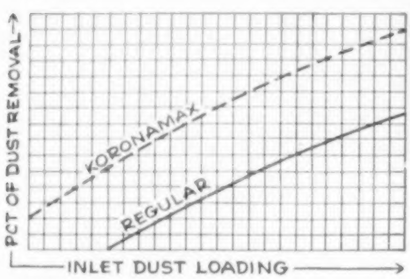
☐ Item A-1 ☐ Item A-2 ☐ Item A-3 ☐ Item A-4



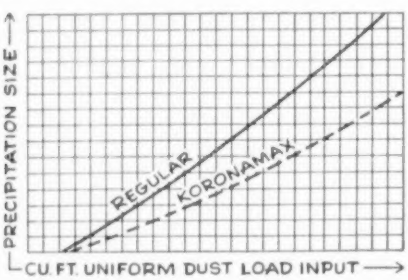
Another Koppers Exclusive in ELECTROSTATIC PRECIPITATION



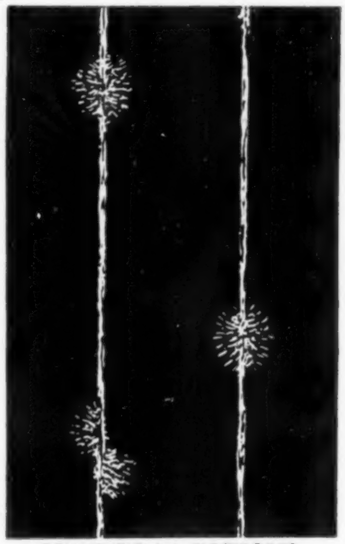
INCREASED POWER—The evenly spaced discharge points of "Koronamax" Electrodes reduce the arc-over tendency and permit increasing power input.



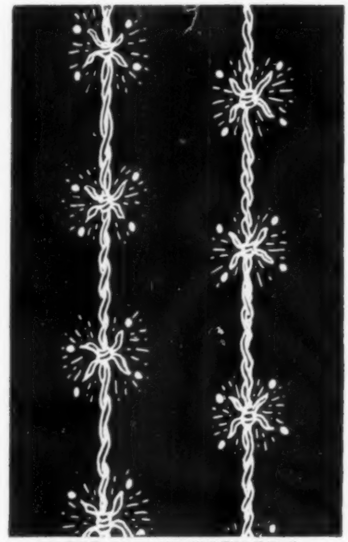
HIGHER EFFICIENCY—Replacement of regular electrodes with "Koronamax" Electrodes allows higher power input — greatly increased efficiency.



SMALLER SIZE—In new installations desired efficiency may be obtained with smaller unit when "Koronamax" Electrodes are used.



CONVENTIONAL ELECTRODES



"KORONAMAX" ELECTRODES

"KORONAMAX" ELECTRODES increase efficiency and capacity of electrostatic precipitators

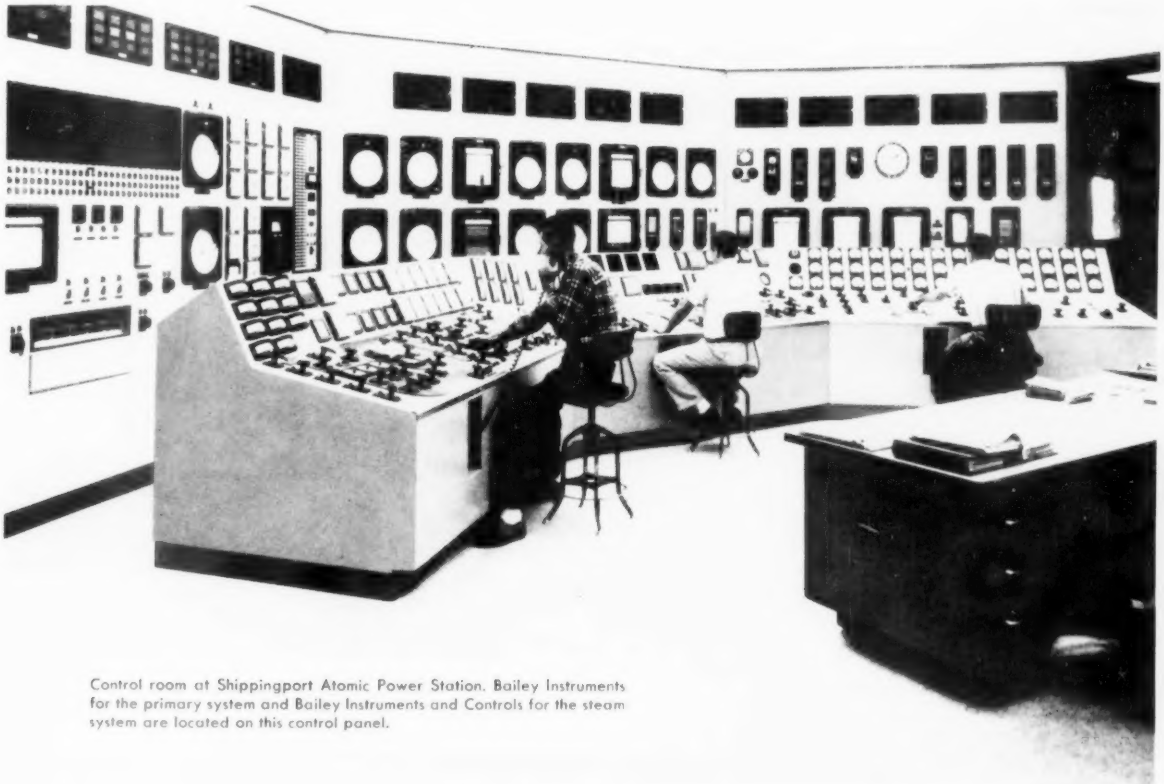
"Koronamax" Electrodes developed by Koppers are now in service in several different applications and their *controlled* corona discharge has resulted in greatly increased capacity and efficiency. This unique type of precipitator electrode may solve *your* gas cleaning problem.

Koppers' experience, constant research and extensive field testing have led to this important advance in precipitator design. Check with Koppers to see if "Koronamax" Electrodes can help you get top precipitator efficiency. For more information, write: Koppers Company, Inc., 4401 Scott Street, Baltimore 3, Md.

KOPPERS

ELECTROSTATIC PRECIPITATORS

Engineered Products Sold with *Service*



Control room at Shippingport Atomic Power Station. Bailey Instruments for the primary system and Bailey Instruments and Controls for the steam system are located on this control panel.

Bailey pioneers the control of . . .

ATOMIC STEAM POWER PLANTS

This control room is the center of operations for the world's first full-scale atomic, electric power plant devoted exclusively to civilian use—the Shippingport Station, jointly owned by Duquesne Light Company and the Atomic Energy Commission.

Here, as well as on the atomic-powered submarines, are Bailey Instruments and Controls performing dependably hour after hour, month after month.

In conventional power plants, too, Bailey Meters and Controls are standard equipment. Bailey is the choice of virtually all the most efficient plants on the Federal Power Commission's heat rate report. Here's why:

1. A Complete Line of Equipment

You can be sure a Bailey Engineer will offer the right combination of equipment to fit your needs. Bailey manufactures a complete line of standard compatible pneumatic and electric metering and control equipment that has proved itself. Thousands of successful installations involving problems in measurement, combustion and automatic control are your assurance of the best possible system.

2. Experience

Bailey engineers have been making steam plants work efficiently for more than forty years. Veteran engineer and young engineer alike, the men who represent Bailey, are storehouses of knowledge on measurement and control. They are up-to-the-minute on the latest developments that can be applied to your problem.

3. Sales and Service Convenient to You

There's a Bailey District Office or Resident Engineer close to you. Check your phone book for expert engineering counsel on your steam plant control problems.

A136-1

Instruments and controls for power and process

BAILEY METER COMPANY

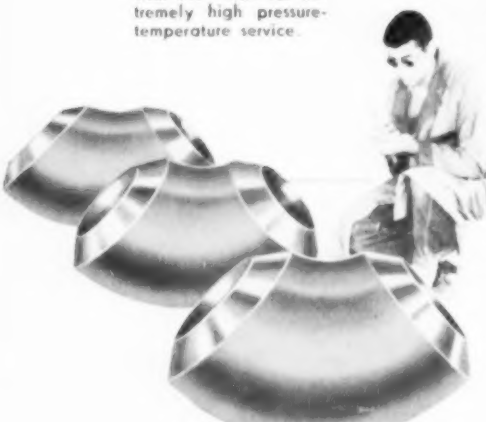
1025 IVANHOE ROAD • CLEVELAND 10, OHIO

In Canada—Bailey Meter Company Limited, Montreal

BAILEY METERS

LADISH

...THE RECOGNIZED, DEPENDABLE SOURCE FOR

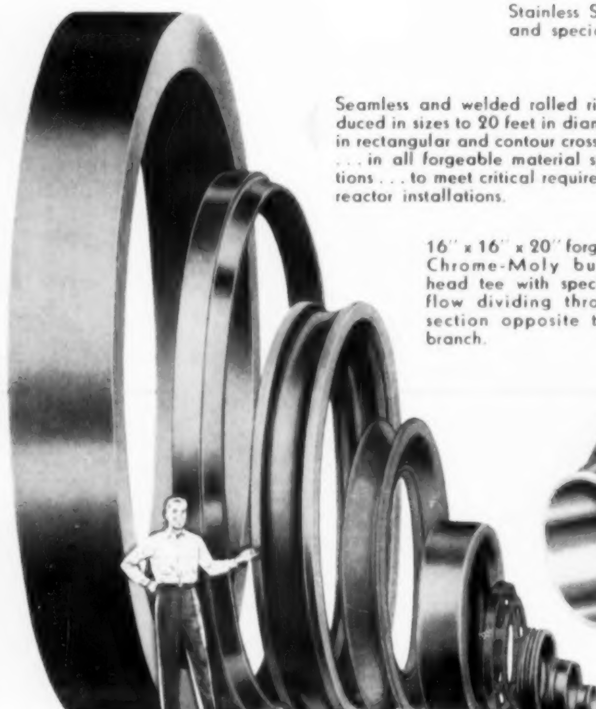


18" alloy steel elbows with 3.9" wall for extremely high pressure-temperature service.

Heavy wall laterals closed impression die forged of Stainless Steel in a variety of sizes.

Stainless Steel, heavy wall, reducing tee with extended run section.

Stainless Steel Elbow with heavy wall and special radius for nuclear service.

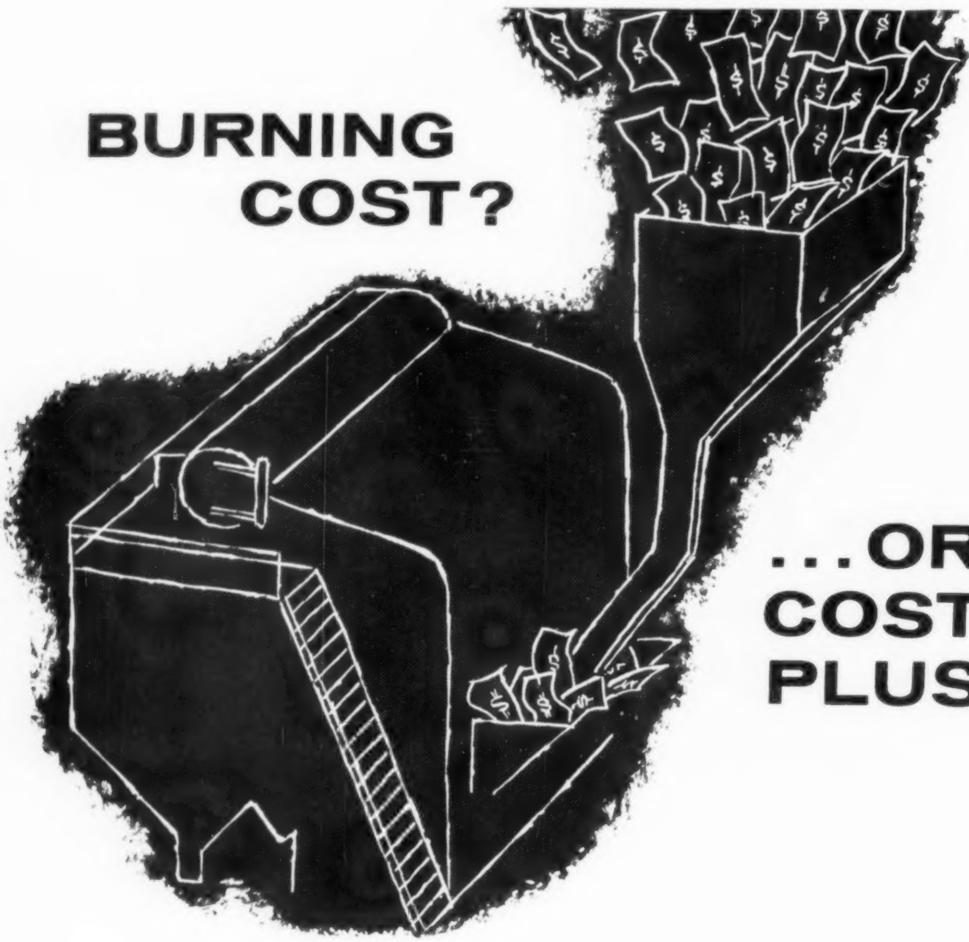


Seamless and welded rolled rings produced in sizes to 20 feet in diameter . . . in rectangular and contour cross sections . . . in all forgeable material specifications . . . to meet critical requirements of reactor installations.

16" x 16" x 20" forged Chrome-Moly bullhead tee with special flow dividing throat section opposite the branch.

Heat exchanger tube sheet of Stainless Steel. Forged weight — 4220 pounds.

BURNING COST?



...OR COST PLUS?

If your boiler, like most, annually consumes its first cost in fuel . . . even a fractional per cent efficiency drop can mean substantial dollar loss.

Holding a boiler to design-engineered efficiency starts with highest standards of operation—continues when these are matched by equally high standards of maintenance.

Apexior Number 1 internal protective coating establishes for the lifetime of any boiler, at pennies-per-square-foot cost, the ultimate in sound, clean surfaces. Apexior-coated tube and drum steel, free from heat-transfer barriers, puts b.t.u.'s to work more efficiently over longer in-service time—thus helps a boiler meet easily . . . or even better . . . designer-operator expectations for economical perfomance.

"The Apexior Number 1 Story" will tell you more about this coating for wet-heat service, simple to apply in one brush coat to boilers, including tube interiors, evaporators, deaerating and feedwater heaters, steam turbines, and all types of pressure vessels using steam for processing. Request your copy — no obligation.

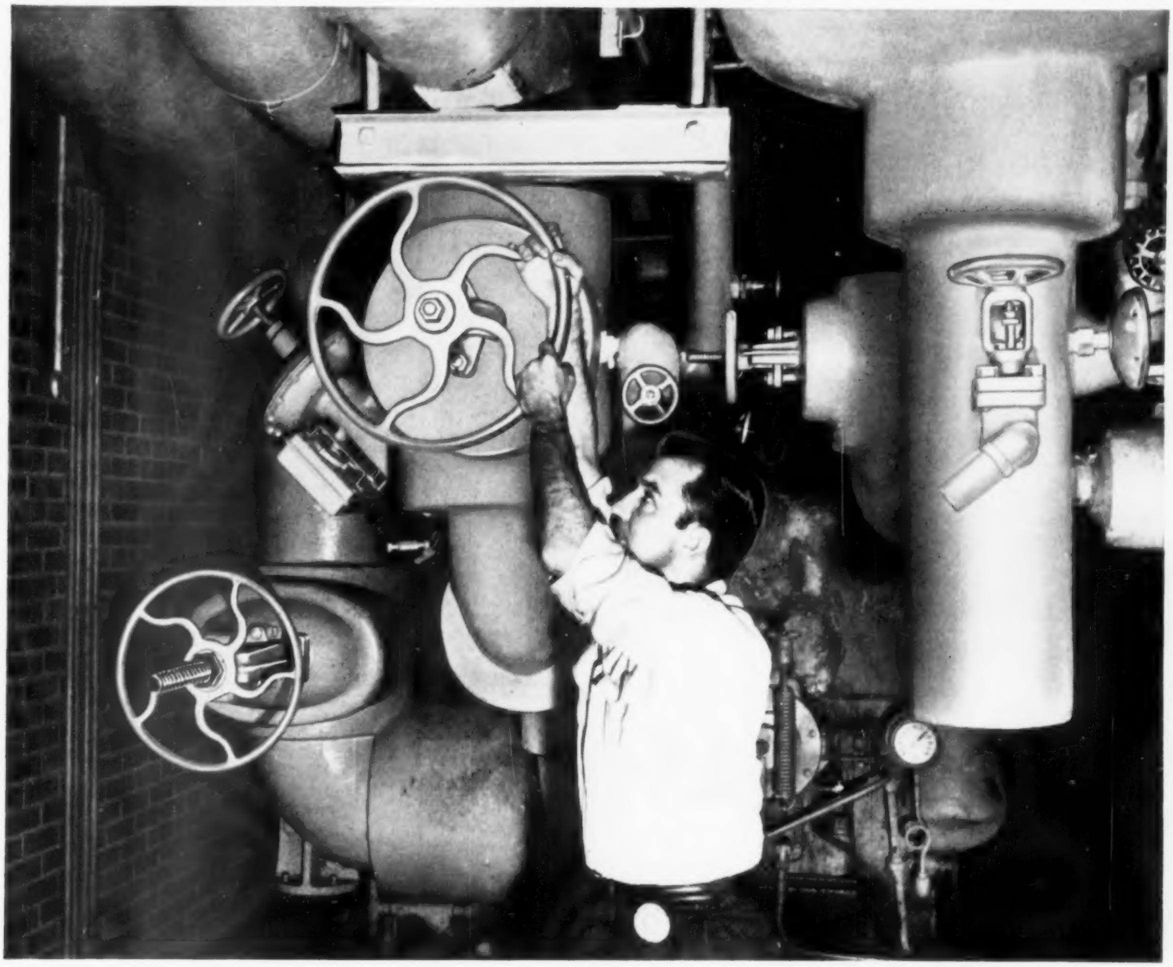
Ask, too, about Dampney silicones and ceramics for dry-heat protection to 1000 F. Dampney Silicone Coating and Thur-Ma-Lox — comprising, with Apexior Number 1, one area of Dampney's specialization in maintenance coatings for metal in corrosive environments.

MAINTENANCE FOR METAL

THE DAMPNEY COMPANY

HYDE PARK, BOSTON 36, MASSACHUSETTS

Cities Service shows how to cut valve costs



Crane globe valve in 14th year on steam turbine line

Cities Service Refining Corp. uses hundreds of valves at its Lake Charles, La., plant. Maintenance and replacement costs could be staggering, but for careful control of valve selection.

For example, the Crane 6-inch, 300-pound steel globe valve shown above was installed at the Lake Charles plant 14 years ago. Working at 250 psi., 600 deg. F., the valve is used in the steam line to a turbine-driven feed-water pump.

In spite of its operation 3 or 4 times a week, this sturdy Crane valve has continued tight in service and has required no repairs in 14 years!

Thrifty buyers want no better reward than the kind of cost-cutting, dependable service they get when Crane valves are installed.

That's why in the petroleum industry, as in all industries, you'll find more Crane valves used than any other make.

This is the valve used on installation above. CRANE 151XR, 300-pound cast steel globe valve for 850 F. maximum temp. Sizes: 2 in. to 8 in. For full details, see your Crane Representative, or write to address below.

CRANE® VALVES & FITTINGS

PIPE • PLUMBING • HEATING • AIR CONDITIONING

Since 1855—Crane Co., General Offices: Chicago 5, Ill.—Branches and Wholesalers Serving All Areas

C-E builds boilers of virtually all designs and types known in present practice . . . in capacities from less than 10,000 to 4,000,000 or more lb. of steam per hr. It is presently building units that will set new world records for capacity, pressure and temperature.

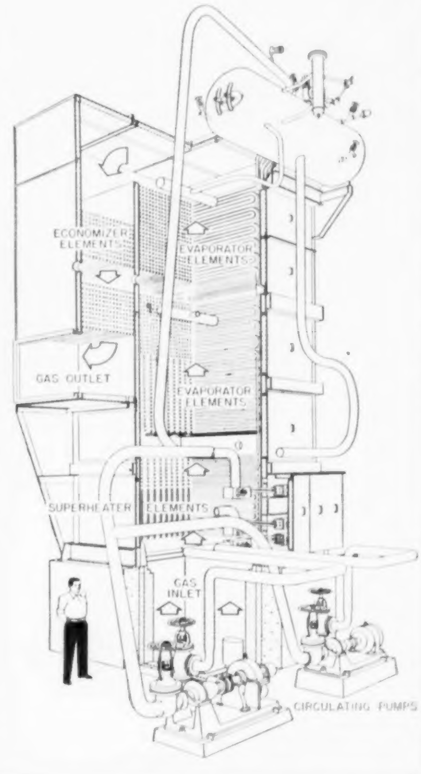
This vast experience has also been successfully applied to the development of many special designs to utilize waste fuels or to meet unusual steam requirements or space conditions.

A few recent examples of special C-E designs which have successfully met unusual problems are illustrated here. In several cases, this success may be attributed to the utilization of exclusive C-E developments such as controlled circulation or tangential firing.

Whether your requirements call for boilers of unusual characteristics, such as those shown here, or for more conventional standard designs, come to C-E where you'll find the skill, experience, facilities—and desire—to meet your needs *exactly*.

For the steel and chemical industries

C-E Package Boiler, Type WCC—a Controlled Circulation design which utilizes waste heat from open hearths or chemical processes. The platen surfaces featured in the first pass permit passage of abrasive or "sticky" gas without erosion or bridging, prolonging boiler life and making the unit easier to clean. Controlled Circulation assures positive control of water to all circuits, permitting a smaller boiler with obvious space-saving advantages. Seven WCC's are now in service; eight others are being erected.



needs – by C-E

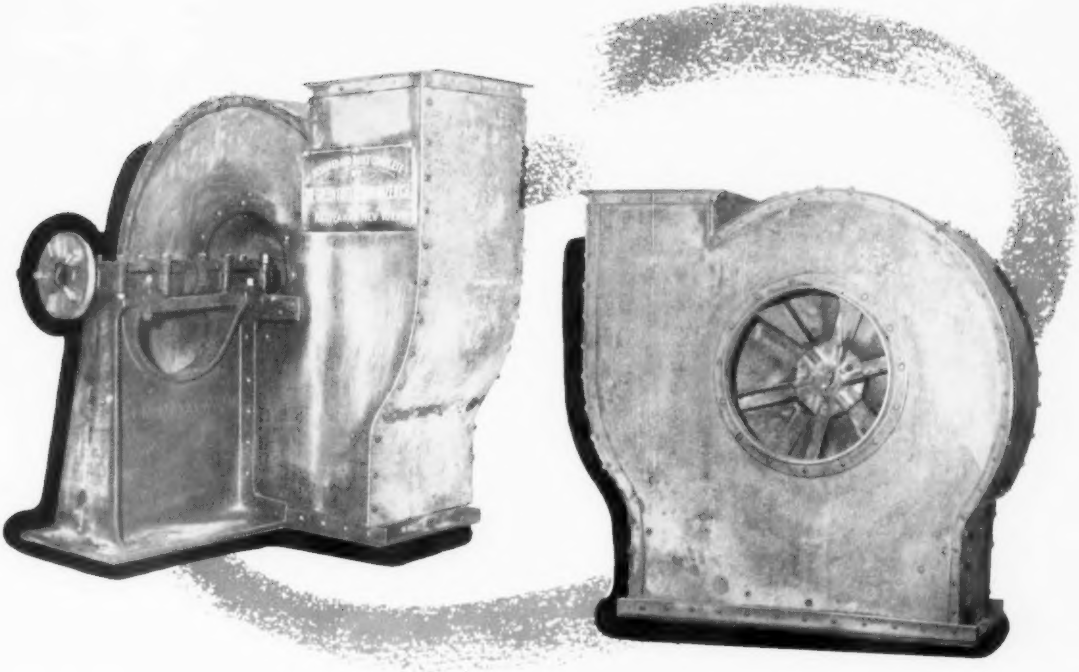
For gas turbine installations

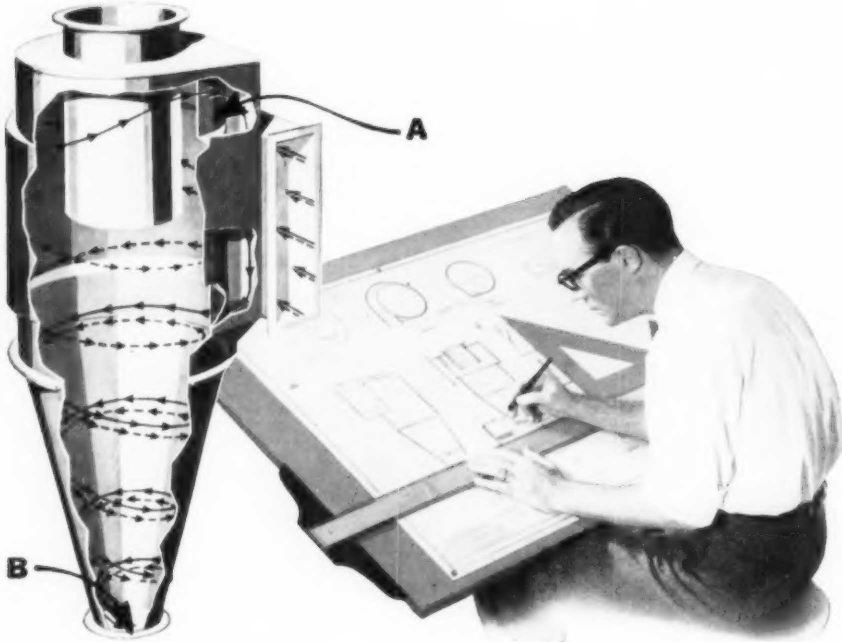
C-E Gas Turbine Boiler—waste heat design for economical utilization of gas turbine exhaust sensible heat. Usable in a choice of cycles to obtain fired or unfired heat recovery and steam generation. Illustrated is a combined cycle, two of which are in service at a chemical plant. Here the turbine is followed by a waste heat boiler, multiple-purpose economizers (process and feedwater), and a conventional oil-fired steam generator which uses a portion of the high temperature exhaust gas for combustion air.

COMBUSTION ENGINEERING

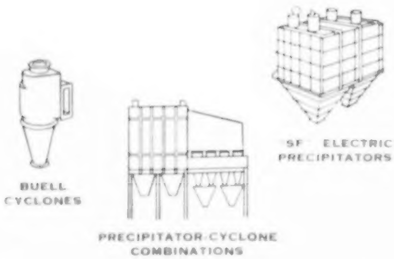
Combustion Engineering Building, 200 Madison Avenue, New York 16, N. Y.

C-195

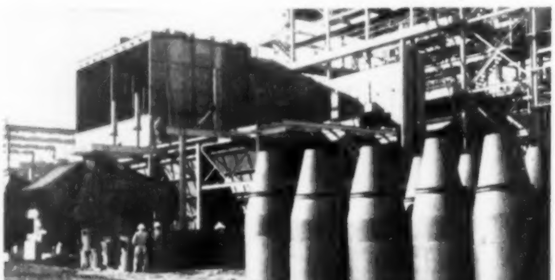




The most efficient operating cyclone collectors made



Design makes the difference: in over a thousand plants across the continent, Buell Cyclones have *proved* themselves more efficient than any other cyclones made. Buell's exclusive Shave-off port (A), traps the extra percentage of dust that ordinary cyclones lose. And large-diameter, (B), custom-engineered design eliminates bridging, clogging, or plugging during operation, keeps efficiency high without interruption. Regardless of your present or planned plant layout, Buell equipment can be designed to solve your dust collection problems efficiently and economically. There's valuable information in a concise booklet, "The Exclusive Buell Cyclone". Write Dept. **70-A,** Buell Engineering Company, Inc., 123 William Street, New York 38, N. Y.



Buell Cyclones before installation at a major plant.

buell®

Experts at delivering Extra Efficiency in **DUST COLLECTION SYSTEMS**

COMBUSTION

Editorial

Man's Conflict With Technical Progress

For those engineers who are actively engaged in the field of steam plant engineering it may be difficult to fathom the meaning of the title of this editorial. Certainly, you will agree, advances in the art of power plant design have made possible more abundant use of electricity at a price to the consumer that has thus far withstood most of the postwar inflationary pressures. In what sense is man in conflict with such progress?

Perhaps it would be best to raise another question, as did Dr. Walter Boveri, president of Brown Boveri Corporation, when he used the above title as the subject of the Town Lecture at the 1958 ASME Annual Meeting. Dr. Boveri, a Swiss banker, economist and business man, asked: "Is it not becoming apparent that real progress of society cannot be measured by the number of automobiles, television sets and washing machines that the community has at its disposal?"

As an industrialist trained outside the field of engineering, Dr. Boveri looks at progress in a much broader sense than material advancement. He conceives of general progress of society as consisting of three components: freedom, progress of man's personality and mind, and technical or scientific progress. It is when there is an unbalance of these three components that man comes into conflict with technical progress.

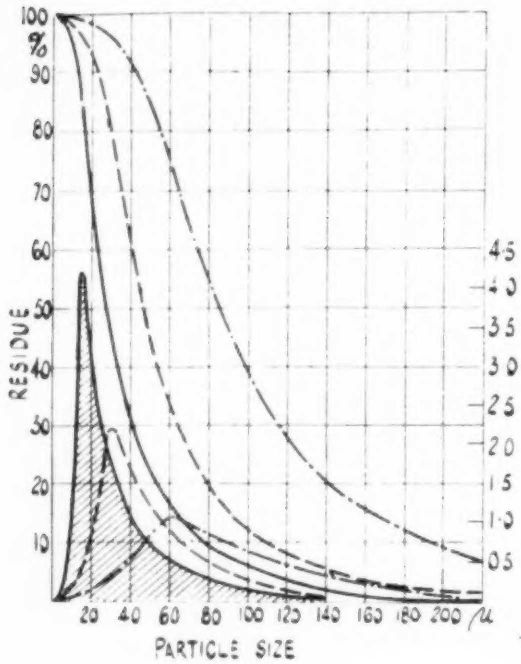
Events of the past several decades have shown that engineers have made substantial technical contributions under the dictatorship of a Hitler and the police state of the Soviet Union. In a sense this is evidence that engineers can work in an atmosphere where freedom is denied and human personality is depraved.

And yet engineers are citizens and human beings. At times it is both necessary and rewarding for them to see themselves as others see them. This is what Dr. Boveri attempted to do in questioning whether technical progress should be regarded entirely as a blessing to mankind. Technical progress has gone a long way to making available the necessities of life and freeing man of the more burdensome physical tasks. But, as Dr. Boveri points out, ". . .what outwardly appears to be of such benefit to man may eventually lead to the destruction of some of his most precious qualities. He may feel that the freedom man set out to gain by the conquest of matter becomes more and more an illusion, because each further step he takes seems to lead him irrevocably and contrary to his intentions into deeper servitude to his new masters: technical progress and materialistic prosperity."

When one really thinks about it deeply, the conclusion is inescapable that man has to live with himself. Technical advances may make life easier but if man becomes so engrossed in them that he is deprived of the solitude that is essential to mental growth, is this progress?

Dr. Boveri urged that parents and teachers should give the closest attention to the development of human qualities of man in an effort to create a higher form of individual being. Such attention is not necessarily opposed to technical progress but can take place side by side with it. He added these thoughts:

"We must, in addition, realize that ingenuity and imagination, those noble qualities of man's mind, can be developed only by strenuous mental training and exercise, sometimes even by hardship; and that intellectual versatility is exclusively obtained by strict discipline of the brain, by endurance and by deep independent thought not only on specialized subjects, but on all the great riddles enveloping our life. However, if man were exclusively to expand his intellectual possibilities in the manner described, he would still resemble only a complicated but soulless device, unless he were also to be taught to open his heart to beautiful things and to human kindness. Finally, man must learn to realize that, surrounding our materialistic everyday life, there lies a metaphysical sphere, which he should try to seek through the arts, philosophy and religion. There he will discover that the deeper meaning of life can consist neither in technical achievements nor in the furtherance of purely materialistic aims."



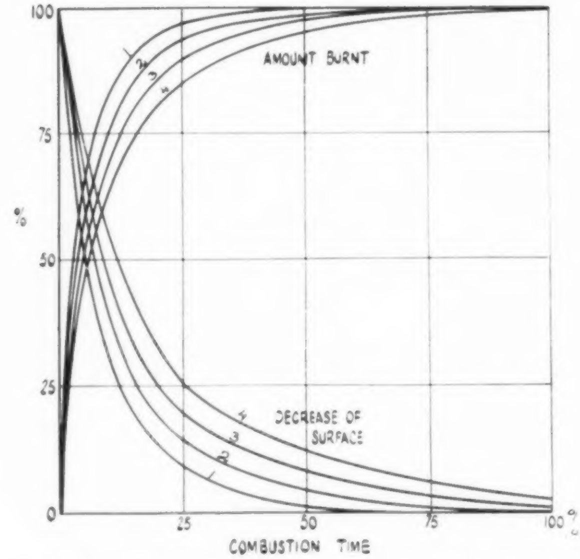


Fig. 2—Curves representing the progress of combustion and reduction of surface of coal dust

Fig. 1—Residue and size distribution curves of coal powders of different fineness

The Mechanism of Combustion of Pulverized Fuel*

Every so often a well-developed paper is presented on the fundamental combustion process experienced by a fuel particle. The author's contribution we feel to be an excellent addition to the literature and one meriting wide circulation both here and abroad.

By P. O. ROSIN

IN this paper a mechanism is defined as an arrangement of a number of different partial processes which are made to act together in a pre-determined way so as to achieve a desired result. The word mechanism implies that each partial process can be controlled, thereby allowing the operator to vary the timing, speed and intensity of the combined action. Mechanism, as here dealt with, further implies that the action must take place in a limited space of defined dimensions, and this has a decisive influence not only on the total time available for its completion, but also on the timetable of each of the constituting processes. This is best made clear by comparing combustion in a large kiln, in the combustion chamber of a gas turbine, and in the cylinder of a piston engine. Although the same kind of fuel may be used and the result in all cases is its combustion, the requirements imposed by space and time are so vastly different that the combustion mechanism bears very different features. Even in the various designs of equipment for burning pulverized fuel in boiler furnaces there may be a difference of mechanism for U-flames, tangential burners, dry-bottom and slag tap furnaces, mill-firing, cyclone furnaces and semi-fluidization.

If these definitions of mechanism are accepted one is forced to the conclusion that, beyond the chemical kinetics of the reactions between oxygen and the constituents of a fuel, there does not exist a "combustion mechanism" in the meaning of a natural law. The process mechanism has, in each case, to be created in order to carry out most efficiently and economically the combustion of a given fuel in a given space and time.

* Paper presented at the Journées de la Combustion des Combustibles Solides et Pulvérisés held in Paris, 4th to 7th December, 1957, by the Institut Français des Combustibles et de l'Energie. The paper is published by their kind permission and that of the Journal of the Institute of Fuel, 18 Devonshire St., London, W1, who published it in their August 1958 issue.

† Number in parentheses refer to listings in References at the end of the article.

The conditions for which the combustion of pulverized fuel is contemplated must be defined, that is the industrial purpose and the type of plant must be specified.

The most important application of pulverized fuel is that of firing large steam boilers; second in importance are cement kilns and certain types of large metallurgical furnaces in which the ash does not cause difficulties. The use of pulverized coal in small combustion units such as shell boilers or in gas turbines presents considerable technical and economic difficulties, and will never attain the industrial importance which it has gained in the field of large steam boilers and cement kilns. Attractive though the problems of high intensity combustion of pulverized fuel in small spaces may be for the research worker, the author must limit himself in this paper to the process mechanism obtaining in the combustion spaces of large steam generating units and—by inference—in kilns and some furnaces. With large steam generating units there are two major tendencies. The first is the emergence as a single operative unit of one large turbine with one large steam generator which has to be available for an uninterrupted period of up to one year. The second is the trend, because of economic necessity, to use coals with ash content increasing up to 15 to 20 per cent without losing boiler or furnace availability.

Apart from the chemical reactions which eventually result in the conversion of the air oxygen into CO_2 and H_2O, the processes involved are:

(1) Aerodynamical (flow of air, gas and dust suspensions, movement of solid particles in gas streams)
(2) Thermodynamical (gas kinetics, heat and mass transfer, radiation)
(3) Physical—chemical (reaction-kinetics, equilibria)
(4) Thermophysical (behavior of coal, ash and slag at high temperatures).

Definition of Pulverized Coal

Before dealing with the place and role of these various processes in the general mechanism, one has to define the properties of "pulverized coal" because they have a profound influence on the mechanism which one has to produce for its combustion.

Coal is not a homogeneous material, neither in its chemical constitution, structure and impurities, nor in its physical reactions to heat. The more research on coal and ash has been carried out the more have the differences in their behavior under the influence of heat become evident. The evolution of volatiles of varying composition at rising temperatures, the different swelling and coking properties which lead to a change of particle size, density, porosity and surface reactivity, the formation of "cenospheres" by some coals during the carbonizing stage of combustion, the liability of others to disintegrate when suddenly exposed to heat, are only a few examples of the bewildering variety with which the investigator of coal combustion is faced. Because of the smallness and isolation of each particle in the pulverized-fuel flame, these changes take place in greater independence than in an accumulation of larger pieces on a grate and lead to different effects.

The pulverizing process itself, far from "homogenizing" the coal, produces particle sizes from less than 1 to more than 100 microns corresponding to surface ratios of at least 10,000 to 1. The size and surface distribution within this range follows an exponential law of general character (1)†: for the residue on a sieve with the aperture x the probability curve

$$R = 100^{-bx^n}\ \% \quad \text{(Rosin-Rammler Distribution Law)}$$

and for the particle distribution its differential curve

$$\frac{dR}{dx} = -\ 100nbx^{n-1}e^{-bx^n}$$

R is the percentage of powder remaining on a sieve having an aperture of x microns

b and n are constants which depend on the kind of coal and type of pulverizing process.

Equation 1 can also be written as (2)

$$R = 100e^{-\left(\frac{x}{x'}\right)^n}\ \%$$

where x is the value of the diameter for which R becomes $100/e = \sim 37$ per cent and therefore characterizes the absolute particle size, and n is the distribution constant which gives information on the closeness of sizing. When n is infinite, all grains have the same diameter, and when n is small the sizes are spread over a wide range and the dust contains a high percentage of fines.

Fig. 1 shows residue and size distribution curves of coal powders of different fineness.

Because surface (its size, nature and availability) is the most important factor in the combustion mechanism of pulverized fuel, the recent investigations on size distribution have laid increasing emphasis on the calculation of total surface. Without going into details, it may suffice to mention the order of magnitude. Pulverized bituminous coal of 25 to 30 per cent volatile matter ground to the fineness at present used in large boiler furnaces, possesses an initial surface of the order of 200 to 300 m^2/kg, much of which is contributed by a relatively small weight of fine dust. For example if there is only 0.1 per cent of dust with a particle size, of 0.1 micron present in 1 kg of pulverized coal, the total surface is increased by 50 m^2. On the other hand, 0.1 per cent of particles of 1 micron account for only 5 m^2. It is this discrepancy between weight and surface fractions which lends to the combustion of pulverized fuel its particular feature.

The initial surface is reduced to that of any ash or slag particle formed during combustion, and if one tries to base the study of the combustion process upon consideration of surface, the conception of an "indicated mean effective surface" has to be introduced, in the same sense as "indicated mean effective pressure" is used in internal combustion engines in which the pressure changes during the process. Theoretical and experimental researches agree that the progress of combustion and the reduction of surface of coal dust in a furnace can be substantially represented by the type of curves shown in Fig 2 (3). The finer the coal has been ground and the higher its volatile content, the steeper is the initial rise in the combustion curve. From the curves the value of the indicated mean effective surface can be obtained which has to be applied in surface kinetic considerations of the combustion process.

† Numbers in parentheses refer to listings in References at the end of the article

Methods and Phases of Coal Combustion

Apart from the combustion of the volatile matter and of the gaseous combustion products CO and H_2 for which the mechanism of gaseous combustion, partly in pre-mixed flames and partly in diffusion flames, applies, all the phases occurring in the combustion of coal are reactions between a solid and a gas. The special features of the combustion of pulverized fuel in contrast to other methods of coal combustion are brought out by the following classification (4):

(*a*) On the grate the coal is in a stationary position fixed by gravity. The air passes through interstices of the fuel bed and reacts with the outer and inner coal or coke surface. Since the flow of gas through beds of broken solids is very irregular, only part of the coal surface is available for the reaction either for aerodynamical or kinetic reasons. The relative velocity between gas and solid is high and the flow itself is turbulent. The action of gravity in keeping the fuel on the grate is enhanced by any caking properties of the coal or the melting of ash.

(*b*) In fluidization the fuel bed alternates continuously between being stationary on the grate and in suspension in the air. While on the grate, the conditions under (*a*) apply. At the moment of lifting, the relative velocity between coal and air decreases but the individual particles are in a state of lively commotion which increases the proportion of available surface. The aerodynamics of fluidization are not yet fully explored.

(*c*) In the classical method of pulverized-fuel firing, the coal dust, is introduced as a suspension in air and remains suspended during the whole combustion process. The aerodynamical laws for the behavior of solid particles suspended in gas apply. A velocity difference between air and particle and between the particles themselves is created which depends on factors to be discussed later. The available reactive surface, inasmuch as it is not covered by ash, is a maximum but the relative velocities between gas and solid, particularly in the later stages of combustion, are low.

(*d*) In the cyclone combustion chamber for coarsely pulverized coal, the fuel is also introduced suspended in an air stream but the larger sizes are separated by centrifugal force and deposited upon the wall of the combustion chamber. They are held there stationary, partly by centrifugal force, partly by the gluing action of molten slag. The air sweeps over their surface at high velocity which, together with the turbulent nature of the flow and the very high temperature, results in a high reaction rate; the available surface, however, is restricted.

Classified as phenomena, the following stages in the combustion process of pulverized coal can be distinguished:

(1) The period before ignition which includes the heating of the air-dust stream and the partial expulsion of volatiles.
(2) The ignition period of the solid residue which normally coincides with the combustion of the volatiles by which it is supported.
(3) The combustion period of the carbonized residue.

Owing to the differences in particle size, relative motion, and location in the furnace these phases are not separated from each other but overlap considerably. In each phase various influences are active simultaneously and if the mechanism depends on several processes in series, such as heating before ignition, or diffusion before combustion, the slowest will determine the reaction rate.

The combustion of the very fine dust, particularly of a coal with high volatile content, resembles more the phenomena in pre-mixed gaseous flames. The ignition of coal itself, particularly if a decomposition into gases, vapors and a solid residue takes place under the influence of heat, is not a well-defined process nor is it possible to relate it to a fixed temperature in the nature of a physical constant of the coal. Time and location of the ignition in a furnace depend on the properties of the coal, its particle size, the preheat of coal and air, the fuel-air ratio, the entrance velocity and direction of the air-fuel jet, as well as on the environmental conditions, amongst which radiation both from the flame and furnace walls plays a prominent role.

Speedy ignition is the key to an efficient utilization of a given combustion space because with the present high entrance velocities of the dust jet, delayed igntion causes not only a considerable loss of combustion space but also a delay in combustion itself, which is no longer assisted by the high initial turbulence of the jet. The means of achieving speedy and stable ignition are well known. They are: limitation of the primary air roughly to an amount needed for the combustion of the volatiles; high preheat of the air; provision of "solid" radiation for coals with low volatile contents for which the combustion of the gases cannot provide a sufficient source of heat particularly at low loads. Yet, although well known, the control of the mechanism of ignition has remained empirical because of its fleeting character and the many factors which influence it.

The combustion of the carbonized residue of larger particles can no longer be described as a homogeneous flame or a flame body as attainable with gases, vapors or very fine dust, in which a balance between the propagation combustion wave and stream velocity is maintained. It is rather the individual burning of suspended particles and this phase of the combustion process becomes of overriding importance for the whole mechanism. The various partial processes have therefore mainly been studied in their bearing on this problem.

Aerodynamics and Thermodynamics

Since the process of burning pulverized fuel generates and transfers heat in a moving gaseous medium, aerodynamics and thermodynamics become inseparably linked.

The coal dust occupies less than 0.01 per cent of the volume of its air requirement for combustion. Aerodynamically, such a suspension behaves like a gas, possibly showing a slightly increased apparent viscosity, and the laws governing the movement of solid particles in gases are operative. On the differential velocity between dust and gas depends not only the heat and mass transfer by forced and natural convection and molecular diffusion, but also the time of residence of each particle in the combustion space.

In 1933 the author presented a paper on "Lois Dynamiques de la Combustion" to the III^e Congrés du Chauffage Industriel. This paper also dealt with the

aerodynamics of the combustion of pulverized fuel and mentioned that differential velocities could be caused by:

(*a*) gravity leading to a differential velcoity known as terminal velocity of a falling sphere in a gas,
(*b*) centrifugal forces in eddies under conditions of turbulence,
(*c*) buoyancy forces due to the higher temperature of the envelope of hot combustion gas.

To this must be added:

(*d*) the mechanical thrust exercised on a particle by the igniting volatiles.

These differential velocities have a twofold effect; they break up, or at least reduce the thickness of, the gaseous stagnant layer at the surface, and once accelerated by any of these forces the higher inertia of the particle allows it to leave its gaseous envelope and find fresh supplies of oxygen. It should be realized that, assuming a uniform distribution of dust in its theoretical volume of combustion air, a particle of about 60μ diameter is just contained in its theoretical volume of combustion air. All smaller particles—for the usual fineness the vast majority by number and about 50 per cent by weight—therefore find their air requirements in their immediate vicinity whereas the larger particles depend on differential velocities for their full air supply.

The most comprehensive formulae for the terminal velocity due to gravity of falling spheres of coal in air and combustion gas of various temperatures and viscosities for Reynolds numbers between 0.6 and 2500 have been developed by W. Gumz (5), and valuable conclusions about the time of residence of particles in the furnace gas for upstream, downstream and horizontal flow may be drawn therefrom. Gumz has also calculated the correction to be made if, by the formation of cenospheres of swelling coals, the volume of the particles increases and their density decreases, or if by water evaporation shrinking occurs.

To quote merely orders of magnitude: the terminal velocity at 1000 to 1250 C gas temperature of the largest dust particles of about 0.2 mm found in presentday pulverized-fuel practice, is approximately 0.4 to 0.5 m/sec which therefore is the maximum differential velocity between particle and gas which gravity can produce. The corresponding figure for the most frequent size fraction, the diameter of which according to Fig. 1 is only about one-sixth of the largest size, is no more than 0.1 m/sec. These are initial values related to the initial size of a particle, and as its size is reduced during combustion, the terminal velocity decreases.

The mean flow velocity of the gas body in the combustion space of a large boiler at these temperatures lies between 6 and 9 m/sec, and it is in these regions of gas and differential velocities that laboratory measurements of the reaction rate would be most valuable. Unfortunately most of them have been carried out at much higher relative velocities.

It has often been overlooked in calculations of the relative movement of coal dust particles in a combustion space that a burning particle is surrounded by an envelope of hot gas, the temperature of which may be considerably higher than that of the surrounding atmosphere. The differential density creates strong buoyancy forces which may counteract the effect of gravity and even reverse it.

In comparison with the differential velocities due to gravity, those due to centrifugal forces in eddies may be considerably greater and also lead to far greater velocity differences between particles of different size. Turbulence as the promoter of small eddies in which great centrifugal forces are operative is, therefore, the paramount requirement for a high rate of combustion of large particles. Here one must distinguish between natural and artificial turbulence. Natural turbulence is a property of flow, independent of external influences. Various portions of the gas no longer follow the general direction of flow but roll themselves up and proceed as eddies, a state characterized by a certain value of the Reynolds number. However, calculating the Reynolds number for the immediate surrounding of a particle from

$$Re = \frac{\text{terminal velocity} \times \text{particle diameter}}{\text{kinematic viscosity of combustion gas}}$$

for temperatures between 1000 C and 1250 C, one arrives at values below 1, which are far too low to indicate any turbulence in the immediate vicinity of a particle.

The creation of eddies and centrifugal forces depends, therefore, on artificial turbulence by adequate burner construction and judicious introduction of secondary and tertiary air. None of these eddies is, however, long-lived because their energy is quickly consumed by the acceleration of the dust particles and by friction. Artificial turbulence is also produced by the sudden expansion of gas during combustion and the buoyancy of burning particles, particularly where a large number of particles is burnt simultaneously as in the first half of the combustion space. The effect of all this is, therefore, that turbulent conditions will exist during ignition and in the first period of combustion but that for the burning of the larger coke particles one becomes dependent on diffusion as the main source of oxygen supply.

Although one can thus describe qualitatively the various aerodynamical phenomena during the combustion of pulverized fuel, they cannot be treated quantitatively. For the combustion of pulverized coal does not take place in an orderly way so that, for instance, the terminal velocity alone would determine the relative movement of the particles. Complicated local flow patterns aided by large differences and changes of temperature arise and disappear so that no equation defining the state of either the gas body as a whole or in the vicinity of an individual particle can represent the true aerodynamical and thermodynamical picture. All that can be done is to approach the problem as a statistical integration using mean velocities, temperatures and conditions of flow.

Kinetics

A fundamental factor in the design and performance of pulverized-fuel installations is the total time of combustion t_c of a particle in relation to the time of its residence t_r in the combustion space. Since the combustion time of small particles is short, it is for the larger size fraction that this relation becomes important. In order to avoid carbon losses and deposits on the convection cooling surfaces, the relation $t_r > t_c$ should be observed for at least 98 per cent of the dust.

The time of residence depends mainly on the aerodynamical factors; the time of combustion is controlled by an interdependence of aerodynamical, thermodynamical and chemical influences. Whereas the combustion of the volatile matter and of the very fine dust follows the mechanism of a homogeneous gaseous reaction, the combustion of the non-volatile coal substance is a heterogeneous reaction which, in the last instance, depends on the availability of oxygen at the reacting surface. The type and rate of the various phases occurring in heterogeneous reactions depends on temperature and time, and the total turnover of substance is proportional to the available size of its reacting inner and outer surface.

The conception of a reaction rate, expressed, for instance, as mg coal burnt per cm^2, however, cannot apply to the first stage of the combustion of pulverized coal when the volatiles are burning outside the particle and the fine dust behaves more like a gas. It can only apply to the burning of the carbonized residue of the larger particles and their reaction kinetics have been the object of both experimental and theoretical studies. However, in view of the confusing effect which particle size and shape, coal constitution and ash may have on the results, experiments were mainly carried out with selected spheres of pure carbon or in carbon tubes under strictly defined aerodynamical conditions. One may assume that the rate of reaction of an ignited coke particle plotted against the progress of the reaction toward completion, has the general character shown in Fig. 3 (6).

At the beginning oxygen is plentiful and turbulence is high but the temperature is still low; toward the end oxygen is scarce, turbulence is low, the influence of the ash may make itself felt and the temperature is falling. The maximum rate is reached at a certain ratio of surface temperature and oxygen availability. The actual temperature besides being a function of the oxygen supply depends also on the secondary reactions (Boudouard, dissociation), on particle size and on the heat transfer to and from the particle by convection and radiation. In a combustion space for pulverized fuel, however, the first part of this curve is preceded and influenced by the combustion of the volatiles and the fine dust which quickly raises the temperature to a peak, while consuming much of the oxygen immediately available to each particle. This results in a momentary oxygen shortage for the larger carbonized particles until they escape from the flame of burning gas and fine dust into regions where oxygen is still available. Hence, there should be two maxima in the heat release (temperature) of a burning coal particle, the first during the combustion of its volatiles, the second at the beginning of the combustion of the carbonized residue when it still finds sufficient oxygen and the ash does not yet interfere with the burning rate. This has, in fact, been observed by Orning (7).

It has long been known that, because of the exponential nature of the reaction rate of combustion:

rate $= Ae^{-c/T}$ (A and c constants, T absolute temperature)

the chemical resistance at practical furnace temperatures is so small that the actual rate is controlled solely by the supply of oxygen to the reacting surface. Dependent on the environmental conditions of a particle, this takes place by diffusion, convection or a combination of both. It was, however, not fully established

(1) whether the primary reaction is

$$2C + 2O_2 = 2CO_2$$

or

$$2C + O_2 = 2CO$$

in which latter case only half of the weight of oxygen has to be supplied to a given weight of carbon as in the combustion to CO_2,

(2) what the size and availability of the outer and inner reaction surface is as a function of both temperature and behavior of ash,

(3) how the chemical resistance and reactivity of various carbonized coals change with temperature, and whether ultimately all coke residues show the same rate of reaction,

(4) in what proportion diffusion and convection contribute to the oxygen supply at the various stages of combustion,

(5) how the reaction rate depends on the absolute size of the particle.

Recent research has made some notable contribution toward answering these questions. It has been experimentally proved (8) that at temperatures exceeding 1100 C, carbon monoxide is the primary product of combustion, either directly or involving the Boudouard reaction. This leads to the conclusion that the combustion of CO to CO_2 takes place as a secondary homogeneous gas reaction so that there are actually two "combustion fronts," the first on the surface of the particle, the second at some small distance where CO and H_2 meet the oxygen. The existence of such a second front would help by radiation, to maintain a sufficiently high temperature of the particle surface, but would also act as a screen for the incoming oxygen and thereby slow down the rate of the surface reaction.

Wicke and his collaborators (9), in their combustion experiments inside a carbon tube, have established three temperature stages in the combustion process of carbon, during each of which different factors control the re-

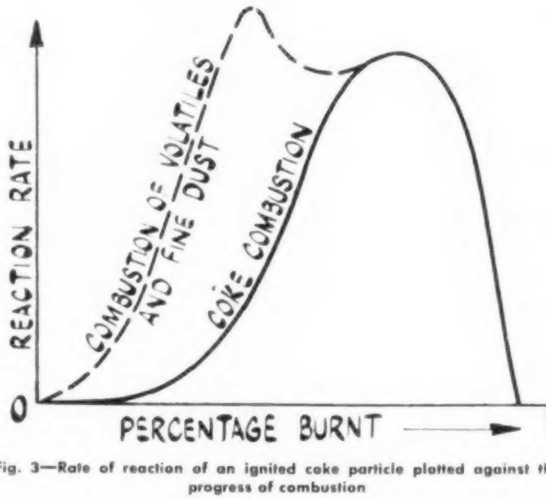


Fig. 3—Rate of reaction of an ignited coke particle plotted against the progress of combustion

action rate. At relatively low temperatures (500 to 600 C) at which the whole external and internal surface of the carbon material is available for sufficient oxygen, the reaction rate is purely chemically controlled and possesses a high activation energy. At medium temperatures (750 C) the chemical rate increases but the participation of the inner surface diminishes, resulting in an apparent lower activation energy. At high temperatures (above 1100 C) at which the chemical reaction rate is high, the actual rate is determined by the transport of oxygen through the boundary layer to the carbon.

The statement that at high temperatures the chemical resistance becomes negligible, does not mean (10) that it has yet been proved that any differences in the reactivity of the coke residue from different coals disappear at high temperatures, and that therefore the rate of reaction measured on a pure carbon surface is the same for different carbonized coals. Their reactivities and the influence of ash on them under practical combustion conditions are largely unknown.

The first and second stage of Wicke correspond roughly to the pre-ignition and ignition stages of pulverized coal fed into a combustion space, during which the expulsion of the volatiles, their ignition and the ignition of the coke residue take place. The third compares with the combustion of the residue of carbonized coal when oxygen moves toward the particle, whereas CO and H_2 move away from it. This mass transfer can take place by forced or natural convection due to the relative motion between particle and gas, and by molecular diffusion. Since at the same time heat is transferred to and from the burning particle, the Reynolds analogy between mass, heat and momentum transfer may be applied. Under these assumptions several attempts have been made to calculate the rate of reaction or the time of combustion of a sphere of coal or carbon, and to compare the calculated results with those obtained by experiments or with measurements on large-scale plant. Whereas the earlier attempts assumed a laminar boundary layer through which the transport of oxygen could only take place by diffusion, Gumz (5) has based his calculation of the combustion time of coal spheres on the assumption that the mass transfer is convective, meaning that by analogy with the corresponding laws of heat transfer, the diffusion is included. His results, which take into account the decrease of diameter and oxygen supply, are in fairly good agreement with experimental and practical measurements.

Godsave, (11) using Froessling's semi-empirical equation for the mass transfer as a function of the Reynolds and Schmidt numbers, has recently made an interesting attempt on these lines to relate the reaction rate of burning carbon particles of different size to the surrounding flow and diffusion criteria. For example, for carbon spheres in air at a representative mean gas film temperature of 1200 C the rate of the reaction $C + O_2 = 2CO$ may be expressed by the non-dimensional equation

$$F = 0.347\,(1 + 0.276 Sc^{1/3} Re^{1/2})$$

in which F is a non-dimensional reaction rate factor

$$F = \frac{Sd}{\rho D}$$

with

S = specific reaction rate at the surface of the sphere (g cm^{-2} sec^{-1})
d = diameter of the sphere (cm)
ρ = density of the gas (g cm^{-3})
D = coefficient of diffusion of oxygen in the gas (cm^{2}sec^{-1})
Sc = Schmidt number
Re = Reynolds number

The Schmidt number is a non-dimensional criterion for mass transfer by diffusion and is defined as:

$$Sc = \frac{\text{absolute viscosity of gas}}{\text{density of gas} \times \text{diffusion coefficient}}$$

In order of magnitude, for oxygen in air

$$Sc_{1000}\,C = 0.951$$
$$Sc_{1200}\,C = 0.961$$

The value of the numerical factor 0.347 in Godsave's equation is directly proportional to the partial pressure of oxygen in the free gas stream. It expresses also the highest possible CO content of the gas at the burning surface (10)

$$v\text{CO} = \frac{0.42}{1.21} = 0.347$$

for dry air and pure carbon.

Godsave states that over the range of at least 800 to 1400 C at any given Reynolds number the influence of the gas film temperature on the numerical form of his equation is slight. He has found evident agreement between the theoretical values so calculated and the experimental measurements of Tu, Davis and Hottel (12), and of Smith and Gudmundsen (13), who measured the combustion rate for spheres suspended on wires in an air stream. Table I shows values of the reaction rate for 2 mm spheres as obtained experimentally by Smith and Gudmundsen with carbon spheres suspended on fine wires in an air stream inside a furnace of controlled temperature, and as calculated by Godsave. It also shows approximate values for 0.2 and 0.1 mm spheres calculated according to Godsave's equation. They will apply to an infinite supply of air and take, therefore, no account of the depletion of oxygen occurring in a furnace as the combustion proceeds.

Although these values, which do not account for the decrease of oxygen and the increase of ash with proceeding combustion, are very much higher than those apparent in actual practice, they show one interesting fact: the reaction rate increases with decreasing diameter. It is difficult, at first sight, to reconcile this with the fact that with decreasing diameter the Reynolds numbers become smaller. The explanation can only be that in diffusion, parallel to heat transfer, the gradient is inversely proportional to the diameter. This accelerating effect greatly outweighs the retarding effect of lower terminal

TABLE I VALUES OF REACTION RATES FOR SPHERES

Diameter, mm	Temperature, C	Differential Velocity, cm/sec	Reaction Rate, mg cm^{-2} sec	Author
2	1000	30	2	S. and G. Godsave
0.2	1200	45 (terminal)	11	Godsave
0.1	1200	10 (terminal)	20	Godsave

velocities and lower Reynolds numbers, which latter is so small anyway that it can have no influence. It further shows that diffusion under these conditions is by no means a slow process as has often been assumed.

It must be emphasized that Godsave's equation gives the rate of reaction only for the particular diameter to which it is applied. In order to obtain a mean reaction rate over the whole lifetime of a particle one has to integrate between its initial and final diameter; in addition, to make the values comparable with conditions in a furnace one has to integrate over the decreasing oxygen concentration between 21 per cent and the final oxygen in the combustion gas according to the excess of air used for combustion

In Fig. 4 the ratio between the actual reaction rate at any moment of the combustion and the initial rate[1] has been plotted against the progress of combustion toward completion. The curves have been calculated for various excess air percentages ranging from 0 to infinity, this last, therefore, representing the conditions of Godsave and Smith and Gudmundsen. The figure further contains a curve for the ratio between momentary and initial diameter.

These results throw new light on our knowledge of the final stages in the combustion of coke particles in a combustion space. For combustion with the theoretical amount of air ($n = 1.0$) when free oxygen and carbon disappear simultaneously, the reaction rate is falling continuously and the effect of the rising gradient with decreasing diameter is nil. But already for an air excess of 25 per cent ($n = 1.25$) the drop in the reaction rate with proceeding combustion is considerably less and turns over into an increase toward the end. This is still more pronounced at 50 per cent and 100 per cent air excess ($n = 1.5$ and 2); for the latter, the initial rate of reaction is nearly constant for the first half of the combustion—falling only about 5 per cent, and then increases in the second half, particularly the last stage.

The inference to be drawn from these curves is that the accelerating action of tertiary air supplied at an advanced stage of combustion is less due to any aerodynamical effect than to the strong effect on very small particles of higher oxygen concentrations.

This picture does not yet take notice of the effect which the increasing ash content of a burning particle may have on the reaction rate. There may be catalytically accelerating effects and there may be a delaying influence by covering the carbon surface with a layer of ash or slag. Except for the conclusions which one may draw from the carbon content and microscopical examination of flue dust, no experimental data on the tail end of combustion seem to be available. Since, from a practical aspect, the final phase of combustion in a furnace is often the most important one, it is hoped that future research will fill this gap in our knowledge.

Accelerating factors in the combustion mechanism are therefore:

- temperature—up to about 1000 C,
- volatile matter,
- turbulence,
- oxygen excess,
- diminishing particle size.

[1] The initial burning rate is the rate of combustion of the original ignited carbon particle at a given temperature (1200C).

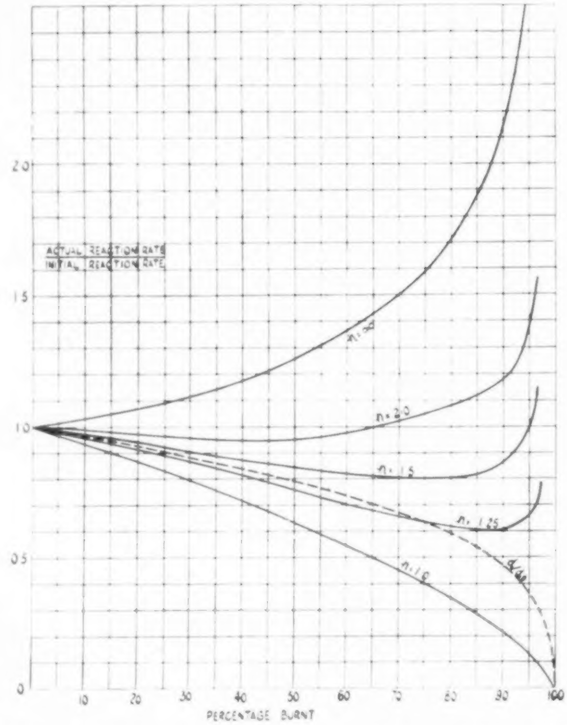


Fig. 4—Ratio of actual reaction rate at any moment of combustion to initial reaction rate plotted against progress of combustion

Retarding factors are:

- surface layer,
- falling oxygen concentration,
- heat loss by radiation below 1000 C,
- ash.

Finally, it should be mentioned that although the curve for the reaction rates may be similar for all particle sizes, the wide size distribution of pulverized fuel causes the maximum rates to be reached at different times, at different distances from the burners and for different periods of duration. This is the more so as in many practical designs such as tangential firing, the corner burners are arranged on top of each other and can be tilted, which results in the staggering and overlapping of the successive phases and leads to various times of residence of the particles in the furnace. The separation of the various stages becomes thereby less pronounced and the overall combustion intensity expressed, for instance, as heat release in time and space becomes more uniform.

Specific Heat Release

So far the influences which the various partial processes exercise on the time of residence and on the rate of combustion have been dealt with. But, as stated in the introduction, the combustion mechanism must also be related to space and this relation finds its statistical expression in the specific heat release per m³ combustion space and hour. It can be expressed as (14, 15):

$$Q = 3600 \frac{C_N}{V} \frac{273}{T} \frac{1}{t_g}$$

or approximately

$$Q = \frac{C_N}{VT} \frac{1}{t_g} 10^6 \text{ kcal m}^{-3}\text{h}^{-1}$$

with

Q = specific heat release in kcal per m^3 combustion space an hour
C_N = the net calorific value of the fuel in kcal/kg
V = the volume of combustion gas arising from 1 kg of fuel $nm^3\ kg^{-1}$ (0° C, 760 mm)
T = the mean absolute temperature of gas in the furnace in ° C
t_g = the time of residence of the combustion gas in the furnace in seconds

Thus, if $t_g = 2$ seconds, there will be 1800 gas changes per hour. The term $1/t_g$ may also be called "space velocity."

For a particle which moves with the same velocity as the gas, the maximum time of residence available for combustion is that of gas residence. Any longer combustion time means unburnt coke being carried over into the convection part of the boiler. Longer times of residence due to lower velocities of the particles, or shorter times of combustion allow more fuel to be burnt. This will raise the temperature and velocity of the gas, and the limit is reached when either the furnace leaving temperature becomes too high or the combustion time of the largest particles exceeds their time of residence. The ratio

$$\frac{\text{time of fuel residence}}{\text{time of gas residence}}$$

in the rising gas stream of boiler furnaces may be of the order 1.05–1.10 but is very much higher in cyclone furnaces, in which the time of fuel residence is increased by centrifugal forces and by the adhesion to the liquid slag. Very high heat releases can, therefore, be obtained in the cyclone proper. Owing to this and the limited cooling possibilities, however, the gas leaving the cyclone and carrying still unburnt dust with it needs additional combustion and cooling space.

The specific heat releases in large steam generators with capacities of 50 to 100 Mw are of the order of 220,000–180,000 kcal/m³/h whereas in the period between the wars heat releases in smaller boiler units of 25 to 30 Mw of 300,000 to 250,000 were usual. All these values are considerably lower than those which can be derived from the reactions rates previously discussed. The question arises, therefore, whether it is desirable and possible to conduct the combustion mechanism in the furnaces of large boilers in a way which would increase the apparent reaction rate and specific heat release. The object would be to reduce the capital cost of the unit by reducing the size of the combustion space. The means which follow from equation (for specific heat release, above) are well known: limitation of excess air, lowering of the mean gas temperature and shortening of the ignition and combustion time. With the present furnaces already operating with only 25 to 30 per cent excess air, there is little scope for further reduction, particularly since this, as Fig. 4 has shown, will slow down the reaction rate. Lowering the mean gas temperature by 100 C from 1500 to 1400 C abs. increases a heat release of 200,000 by about 7 per cent, but this means increasing the radiation at a lower temperature difference without increasing the radiation-cooling surface by higher flame emissivity and cleaner radiation surfaces of higher absorption capacity.

The shortening of the ignition and combustion time by aerodynamical means, namely the acceleration of heat and mass transfer, and their limitations toward the end of the particle life, has already been discussed. There remains only the reduction of particle size by finer grinding, and it is well known from the experiments with pulverized-fuel-fired locomotives and gas turbines that heat releases of several million kcal/m³h, corresponding to combustion times of only 0.1 to 0.2 seconds, can be obtained for relatively short periods in combustion chambers with high surface/volume ratios, clean cooling surfaces, fine grinding and the admission of a small percentage of unburnt carbon. For large boiler furnaces, however, these premises do not apply.

The development of pulverized-fuel firing has been a constant search for an economic balance between grind-cost, capital cost for combustion spaces and boiler availability. It has been found by experience, that large combustion spaces are at present the most economic way to keep the pulverizing costs down and to lengthen the periods of boiler availability. In fact, boiler availability has assumed overriding importance and demands—for solid as well as liquid fuels—a limitation of the gas temperature to no more than about 1100 C at the entrance into the convection-cooling surface. Any increase of the specific heat release by finer grinding could only be considered if it were achieved without raising the pulverizing costs and without increasing the furnace-leaving temperature. Neither conditions can at present be fulfilled.

Crossley and Marskell (16) in a recent survey of the work of the British Boiler Availability Committee state, among other recommendations to minimize the formation of bonded high-temperature deposits, "that the temperature of the combustion should be as low as possible to reduce the extent of vaporization of chlorine, that the furnace should be such that combustion is completed well before the gases pass over convection-heating surfaces and that the temperature of the gas passing over convection-heating surfaces should be kept to a minimum." All this requires large combustion spaces with correspondingly low heat releases.

That under the ever-increasing demands for boiler availability short combustion times cannot lead to correspondingly higher heat releases and smaller combustion spaces is best illustrated by a comparison with oil-fired boilers of the same size. Although the lifetime of fuel oil drops of similar size to that of pulverized coal is 10–20 times shorter, the heat releases in large boiler furnaces are, for reasons of boiler availability, no more than 50 per cent higher. The impossibility of sufficiently rapid cooling makes the exploitation of short combustion times impossible.

A further illustration is the cyclone furnace. As mentioned before it is a high-temperature pneumatic separator in which the larger fuel particles are sifted out and burnt *in situ*. The combustion in suspension is, therefore, only fed with small particles of short combustion time, but in spite of this and the very high heat release in the actual cyclone, considerations of boiler availability have so far not permitted full exploitation.

It is seen, therefore, that the mechanism of combustion in boiler furnaces is bracketed between the economics of

dust preparation and boiler availability. The known pulverizing processes offer little prospect of achieving greater fineness at lower cost. Although our knowledge of the combustion kinetics and of the radiation of pulverized-fuel flames may be enhanced, the arrangement of sufficient radiation-cooling surfaces for increasing boiler size and coals with higher ash content becomes more difficult. It would therefore appear that the mechanism of burning pulverized fuel with high specific heat releases, a mechanism which is potentially existing, can only be exploited if the availability problem at high convection temperatures can be solved. This would be equally important for oil-fired furnaces and mechanical stokers.

It is not within the scope of this paper to examine the thermophysical and thermochemical processes which are the causes of bonded deposits on boiler furnaces, although they are inherent in the combustion mechanism. But one result of recent research which may point to a way out of this dilemma should be mentioned.

Harlow (17) has shown that the cause of the bonded alkali-sulphate deposits is the catalytic oxidization of SO_2 to SO_3 on the convection-heating surface which occurs if the tube temperatures exceed 450 C and which reaches its maximum at about 600 C tube temperature. He is of the opinion that "this effect can be controlled and prevented for considerable periods by surface treatment of the tubes, and that more progress could be made to avoid boiler deposits by preventing the acid formation, than by dealing with its effects."

Any success in this direction would allow the gas to leave at higher temperatures with a corresponding increase in the heat release and a better utilization of the combustion mechanism.

Kilns and Furnaces

Having reached a conclusion in respect of boilers, a comparison with large kilns and metallurgical furnaces fired by pulverized fuel is now appropriate. The introductory statements about coal, ash and particle size distribution apply equally to kilns and furnaces. The kinetics of combustion are the same, but the aerodynamics are different inasmuch as the main direction of the flame is horizontal throughout. The effect of gravity in a horizontal gas stream is to concentrate larger particles in its lower layers and, if time allows, to form a sediment. In a flame, however, this effect is more than outweighed by the buoyancy of the burning particles and the influence of gravity on mass transfer is therefore negligible. On the other hand, the chances of a high degree of turbulence are greater, partly because of the better possibilities of introducing effective jets of secondary and tertiary air into furnaces and partly by the impinging of the flame on the charge.

There is one aspect of the combustion mechanism in furnaces which does not apply to boilers. The point or range of the highest heat release and heat transfer should coincide with that of the highest heat requirement of the process. It requires accurate timing of the ignition and combustion phases by furnace and burner design, preheat and control of the aerodynamics. However, not enough is yet known about the behavior of pulverized-fuel flames as radiating bodies, nor about their emissivity and the role in them of unburnt carbon particles and ash. It is hoped that the IJmuiden (18) experiments of the International Flame Research Foundation will fill this gap.

There are no limitations on the exit temperature from the combustion spaces of kilns and furnaces similar to those existing for boilers. The exit temperature is merely dictated by the kind and thermodynamics of the industrial process. Yet a serious problem of availability may be created by the action of ash and slag on the refractories, flues and regenerators. It appears, therefore, that the various aspects of ash and slag control will acquire growing importance for the combustion mechanism of pulverized coal.

Conclusion

In this paper an attempt has been made to describe the role of the various partial processes which have to be combined to produce an efficient combustion mechanism and to correlate the results of experience with those of research. Although progress has been made on both sides during recent years, there is still a wide gap between them which it will not be easy to bridge, and our knowledge of the happenings in a large flame of pulverized fuel is still scanty.

For a large flame is not just the sum of many single particles, so that its properties and reactions could be predicted from the known reactions of the individuals or from measurements on a small scale. A flame must be considered as a whole, as an entity in which, no doubt, the reactions established in the laboratory take place but which, so to speak, takes the law into its own hand. The combustion of pulverized fuel in a flame is something utterly disorderly. The rapid combustion of the volatile matter and the fine dust, the random movement of thousands of burning particles of varying size, the large differences of temperature, density and viscosity of air and gas, together with the momentum of jets of primary and secondary air, lead to continuously changing patterns which may be explained in detail but can only be dealt with as a whole.

Hence, what really matters in the investigation of the mechanism of combustion of pulverized fuel, after the "microcosm" of burning particles has been elucidated, is the study of flame patterns as the statistical integration of all the partial processes discussed, and the determination of their heat transferring properties. For the problem of utilizing pulverized fuel today is not so much a problem of intensive heat release, as one of accelerated heat transfer and control of the ash.

Acknowledgments

The author wishes to thank Dr. H. R. Fehling for his collaboration, particularly in the calculation of Fig. 4; G. A. E. Godsave, R. H. Gummer and W. F. Harlow for useful discussions; J. Commelin and Dr. W. Gumz for advice on recent publications and the Director of the National Gas Turbine Establishment for making available unpublished Reports.

References

1. Rosin, P., and Rammler, E. "The Laws Governing the Fineness of Powdered Coal." *J. Inst. Fuel*, 1933, **7**, 29-36.
2. Bennett, J. G. "Broken Coal." *J. Inst. Fuel*, 1936, **10**, 22.
3. Rosin, P., and Fehling, R. "Die Feuerungsleistung." *Z. Ver. dtsch. Ing.*, 1930, **74**, No. 13.
4. See also: Townend, D. T. A. "The Combustion of Solid Fuels, and the Aims of Flame Radiation Research in Relation to the Burning of Pulverized Coal." *J. Inst. Fuel*, 1955, **28**, 609.
5. Gumz, W. "Theorie und Berechnung der Kohlenstaubfeuerungen" (Julius Springer, Berlin, 1939). Gumz, W. Kurzes Hand-

buch der Brennstoff- und Feuerungstechnik (Julius Springer, Berlin, 2nd edition, 1953).

6. Cf. Egerton, A., Saunders, O. A., and Spalding, D. B. "The Chemistry and Physics of Combustion." Inst. of Mechanical Engineers and American Society of Mechanical Engineers, Joint Conference on Combustion, October, 1955.

7. Orning, A. A. "The Mechanism of the Combustion of Pulverized Fuel." Institute of Fuel Conference on Pulverized Fuel, 1947.

8. For example: Arthur, J. R. "Combustion of Carbon." *Nature*, 1946, **157**, 732. Arthur, J. R., and Bowring, J. R. *J. Chem. Soc.*, 1949, S1. Wicke, E. "Contributions to the Combustion Mechanism of Carbon. 5th International Symposium on Combustion," p. 245 (Reinhold Publishing Corporation, New York).

9. Rossberg, M., and Wicke, E. "Transportvorgänge und Overflachenreaktionen bei der Verbrennung graphitischen Kohlenstoffs." *Chemie Ingenieur Technik*, 1956, 181–189.

10. Traustel, S. "Verbrennung in der Schwebe." *Feuerungstechnik*, 1941, **29**, No. 1.

11. Godsave, G. A. E. "Rates of Combustion of Solid Fuel Particles." *Nature*, 1953, **171**, 86. Godsave, G. A. E. Unpublished Report, National Gas Turbine Establishment.

12. Tu, C. M., Davis, H., and Hottel, H. *Ind. Eng. Chem.*, 1934, **26**, 749.

13. Smith, D. F., and Gudmundsen, A. *Ind. Eng. Chem.*, 1931, **23**, 277.

14. Rosin, P. O. "The Thermodynamics of the Combustion of Powdered Coal." Proceedings of the 2nd International Conference on Bituminous Coal, 1928. Vol. I, 838–864.

15. Rosin, P., and Fehling, R. "Le Diagramme 'It' de la Combustion" (Dunod, Paris, 1932).

16. Crossley, H. E., and Marskell, W. G. "Boiler Availability." Inst. Mech. Eng. and Am. Soc. Mech. Eng. Joint Conference on Combustion, 1955.

17. Harlow, W. F. "The Formation of Sulphuric Acid in Boiler Flue Gases." American Society of Mechanical Engineers, Annual Meeting, November, 1956.

18. Ribaud, G. M. "Inauguration of Pulverized-fuel Experimental Furnace and Plant at IJmuiden." *J. Inst. Fuel*, 1955, 28 625.

Activity Build-Up in the Primary System of a Pressurized-Water Reactor

By CAPTAIN HARVEY L. ARNOLD, JR.†

U. S. Atomic Energy Commission

ONE generally recognized problem associated with pressurized water reactor systems is that long-lived radioactive deposits tend to build up on the surfaces of the primary loop. On portions of the loop outside the core these deposits may reach levels high enough to hamper maintenance operations. This problem is intensified if stainless steel is used in regions of high flux. Cobalt-60 is produced by n-Y reactions on cobalt 59; and both cobalt-58 and cobalt-60 result from n-p reactions on nickel.

Accordingly, a research program has been undertaken at the Army Package Power Reactor, the first power-producing pressurized water reactor with stainless steel fuel elements and primary system. This work is being done by Alco Products, Inc., Schenectady, New York. Several of Alco's reports are listed as references in the complete paper which is here in abstracted form. The reference list also includes the basic descriptive publication on the APPR.

This paper is based primarily on the reports submitted by Alco. First a brief discussion of attempts to predict the activity build-up through theoretical considerations is given, then a summary of the early experimental work. Finally, decontamination studies related to the problem are discussed.

Activity outside the core could possibly stem from several causes: radioactive fission products from defective fuel elements; fission products from uranium present in the cladding either as an impurity or as a contaminant added during the fuel plate fabrication process; the products of n-∂ or n-p reactions ont he water or impurities in it; or activated corrosion products. The products of water activation are not long-lived; and demineralized water, free from impurities such as Argon-41, is used in the APPR. Therefore, in the absence of serious fission product concentrations, activated corrosion products are the activity source of primary concern. The insoluble corrosion product nuclides with relatively long half-lives are of greatest interest.

† Army Reactors Branch.

These are:

Nuclide	*Half-life*	∂-*energy* (*Mev*)
Co^{58}	72 days	0.81
Co^{60}	5.25 years	1.17
		1.33
Fe^{59}	45 days	1.1
		1.3
Mn^{54}	310 days	0.835
Cr^{51}	26 days	0.267

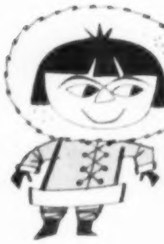
It is important to note that Co-58, not Co-60, assumes dominating prominence when stainless steel cladding is used. Type 304 stainless steel, used in the APPR, contains 8.0–11.0 per cent nickel, 6.0 per cent of which is Ni-59 (n, ∂) Co-60 activation but the nickel is essential.

The ultimate goal of any theoretical approach is two-fold: to predict the activity level of the primary water and to predict the activity deposited on the primary system components. However, the complexity of the many mechanisms in action has so far prevented reliable predictions. As an example, there is fundamental disagreement as to the relative importance of the corrosion products which are activated in the core and then dislodged, and those which come from out-of-flux regions and are activated while passing through the core.

The usual approach has been to attempt to predict the activity of the water (and suspended particles) as a function of reactor equivalent full power hours (EFPH). Various equations have been derived, using the following simple material balance:

Rate of accumulation = rate of formation − rate of removal. An example of such a procedure is found in reference 7. The removal mechanisms incorporated include radioactive decay, purification or filtering, and sometimes deposition on the primary loop surfaces. The equations are recognized as approximations—they are based on assumptions such as a constant ratio of the removal rates due to purification and to deposition, and various relative contributions from in-flux and out-of-flux regions. Further, the equations do not include the effect of n-p reactions, flow rate, temperature, pressure, pH, and many other parameters.

Even if the level of water activity could be accurately predicted, the problem of determining the deposition rate throughout the primary loop would remain.



arctic

or tropic

POWELL

has the right valve!

Handling fluids at sub-zero temperatures or at super-heat – or any of the temperatures in between – is no problem if you install Powell valves. There is a Powell Dependable Valve to meet your most exacting flow-control requirements, no matter what the extremes of your needs.

The complete Powell line includes all types of valves in bronze, iron, steel and corrosion resistant metals and alloys, for pressures from 125 to more than 2500 pounds W.P. Consult your local distributor (there's one in most major cities) or write to:

The Wm. Powell Company • Cincinnati 22, Ohio

Dependable Valves Since 1846

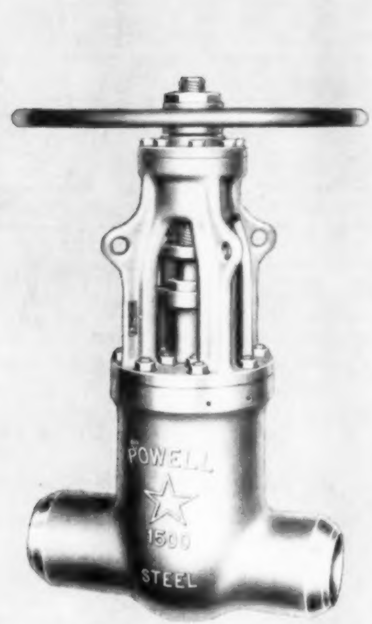


Fig. 11303 W. E.: Steel O. S. & Y. pressure seal gate valve for 1500 pounds W. P. at high temperatures. Powell pressure seal valves are available for working pressures from 600 through 2500 pounds.

Fig. 86190: Steel union bonnet globe valve for 400 W.O.G. Designed for liquified petroleum gas service.

Fig. 2453G: Large 150 pound stainless steel O. S. & Y. gate valve for low temperature service. Can be furnished with interchangeable solid or double wedge disc.

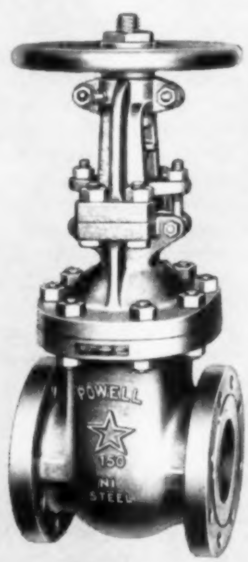


Fig. 1503 Mod.: 3½% Nickel-steel O. S. & Y. gate valve for low temperature service.

POWELL...world's largest family of valves

By IGOR J. KARASSIK*

Worthington Corp.

The boiler feed pump and its associated equipment represent a major operating and maintenance consideration in today's power plant. Here we run in question and answer form a series of clinic sessions on various boiler feed pump problems. The replies are the work of one of the topmost pump authorities and give specific information which we hope will prove valuable to our readers.

Steam Power Plant Clinic—Part V

QUESTION:

Why should it be necessary to warm up a high pressure boiler feed pump prior to placing it in service? I understand quite well that a pump only partially warmed up, that is partially hot and partially cold may be distorted sufficiently to cause major trouble from binding at the close internal clearances. But since high pressure boiler feed pumps are generally of the double-casing barrel type, with centerline support and with suction and discharge nozzles on the vertical centerline, why can they not be started absolutely cold?

ANSWER:

This is a rather controversial question, in that it is very obvious that the answer will be affected by the design of the pump internals. However, some general considerations may be made on this problem.

In the first place, not all methods of mounting the impellers on the shaft are alike. If the impellers are mounted with a slight shrink fit, starting the pump cold will have no injurious effects. If, on the other hand, the impellers are mounted with no interference fit on a shaft the material of which will expand more rapidly than the impeller material, dependence is made on the shrink fit effected when the pump comes up to operating temperature. A cold start in such a case may lead to operation with slightly loose impellers.

The effect of cold starts on the relative position of inner assembly and casing barrel of a double casing pump may or may not lead to difficulties as the following analysis will show. When hot feedwater is suddenly admitted to a cold boiler feed pump, the relative expansion of the outer casing barrel and of the inner element goes through two separate and distinct phases. At first, as the inner element is much lighter than the barrel and is in more intimate contact with the hot feedwater, it expands at a considerably faster rate than the outer casing itself. In order to simplify our analysis, we may even assume that the inner element reaches its

* Assistant to Vice President and Consulting Engineer, Harrison Division

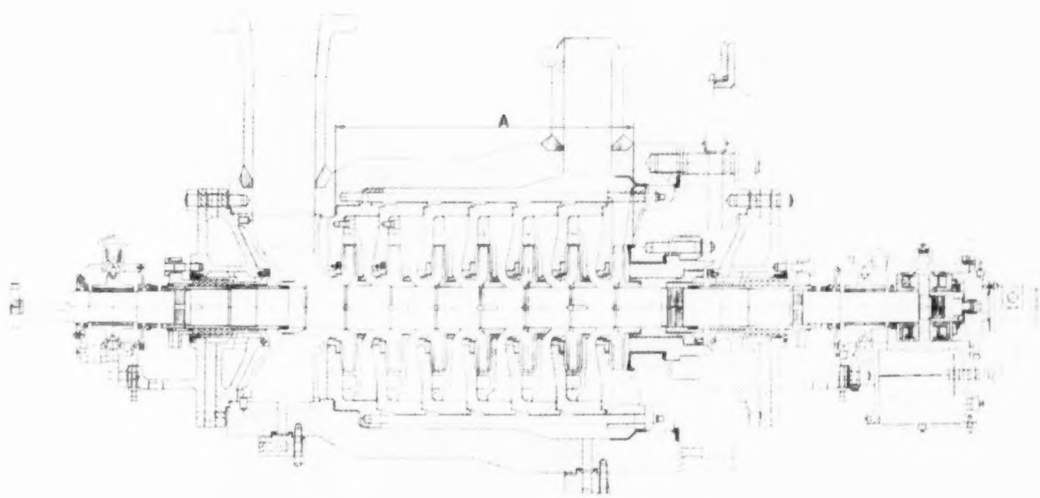


Fig. 1—Inner element of a typical pump identified as "A" in above drawing undergoes relatively rapid expansion with a cold start-up procedure

final temperature before any appreciable temperature change has taken place in the outer casing. Then, as the pump continues in operation, the outer casing heats up and reaches its own final temperature at some later time. If the casing barrel is not lagged, the temperature on its external surface may be somewhat lower than the internal temperature, but we can neglect this difference.

It may be interesting to go through an approximate quantitative analysis of what takes place during these two phases. Let us assume that we are dealing with a 7-stage boiler feed pump, designed to operate at 320 F, that the inner element is of 5 per cent chrome stainless steel and the outer barrel is made of forged SAE-1020 steel. The coefficients of expansion of the two metals in question can be considered to be the same and equal to 0.0000065 inches inch degree F. Let it be further assumed that the length of the inner element within the barrel (dimension "A" in Fig. 1) is 36 in.

If, when the pump is at rest on standby service, the metal temperature is permitted to fall to 120 F, the sudden admission of 320 F feedwater will cause an expansion of the inner element of 0.047 in. This means that by the time the inner element will have come up to its final temperature, it will have expanded forty-seven thousandths of an inch with relation to the casing barrel. Ultimately, the outer casing will also come up to temperature and will expand by an equal amount, nullifying the initial expansion of the inner element.

The effect of this initial relative expansion, followed by a return to the initial relative position of inner element and outer casing, will have different effects on different designs. The effects will depend on whether or not the construction of the double casing pump permits free movement of the inner element within the barrel. If it does, the events which take place will have but little effect on the unit. If, on the other hand, the inner element is constrained within fixed limits, it becomes necessary to interpose some form of compressible gasket between the inner element and either the barrel or the discharge head. (Sometimes these gaskets are incorporated at both points.) It then falls to these gaskets to absorb the difference in expansion we have calculated. Whether a cold start will have an injurious effect on the unit becomes then a question of the reliability of the compressible gaskets and of their ultimate life.

Some consideration should also be given to the effect of the warm-up method selected. It is true that in some cases, the pump will be subjected to a certain amount of distortion because heat may flow unevenly to various parts of the pump. But when warm-up has been properly completed, this distortion should disappear and of course will not have affected the pump while it was at rest. A careful analysis, however, is necessary to check that a pump started up cold does not undergo this type of distortion as it is coming up to temperature, since interference at the running joints or misalignment at the bearings will be a possible cause of trouble.

Thus, in conclusion, it is obvious that some pumps can be started up cold while others should not, but that *all* boiler feed pumps will profit from starting up warmed up if the warm-up operation insures a thorough an even distribution of heat to all parts of the pump.

QUESTION:

We have recently issued specifications for three boiler feed pumps designed for 750 psig discharge pressure. In our desire to purchase equipment with something better than cast iron for the casing material, we specified that pump casings were to be made of cast carbon steel. We were much surprised when several bidders refused to quote cast steel casings and suggested that we choose between cast iron and a 5 per cent chrome steel. We had heard that chrome steels are used for the higher pressure range in boiler feed pumps. Can you tell us what is the reason why cast steel may be unsuitable? Can you also suggest what clues we may look for in our existing installation to determine whether we need to go to more expensive materials than cast iron casings and standard bronze fittings?

ANSWER

The mechanics of corrosion-erosion attack in boiler feed pumps became first the subject of considerable attention in the early 1940's, when it became desirable to use feedwater of a scale-free character. This desire led to the use of lower pH values and to the elimination of various mineral salts which had theretofore acted as buffering agents. As you state, the practice was instituted to use chrome steels throughout the construction of high pressure boiler feed pumps. But this does not mean that limiting this practice to high pressure pumps only is justifiable. It is true that the feedwaters used in the lower pressure plants may not necessarily undergo the same degree of purification. Nevertheless, cases have been brought to my attention where evidence of corrosion-erosion occurred in feed pumps operating at pressures as low as 325 psi.

The exact nature of the attack and the causes leading to it are not, in my opinion, fully understood since minor variations in the character of the feedwater or in its pH seem to produce major variations in the results. At the same time, certain very definite facts have become established:

1. If not necessarily the cause, at least it is recognized that low pH is an indicator of potential corrosion-erosion phenomena.

2. Feedwaters which coat the interior of the pump with red or brownish oxides (Fe_2O_3) generally do not lead to such trouble.

3. If interior parts are coated with black oxide (Fe_3O_4), severe corrosion-erosion may well be expected.

4. When feedwaters are corrosive, cast iron seems to withstand the corrosion infinitely better than plain carbon steel. Chrome steels, however, with a chromium content of 5 per cent or higher withstand the action of any feedwater condition so far encountered. Some manufacturers have a preference for 13 per cent chrome steels for the impellers, wearing rings and other pump parts other than the casing.

If you install boiler feed pumps which are not fully stainless steel fitted, it is important to carry out frequent tests of the pump performance. This step will help you avoid sudden interruption of service. Corrosion-erosion

attack comes on rather unexpectedly and its deteriorating effects are very rapid once the attack has started. If protective scale formation is absent, the products of corrosion are washed away very rapidly, constantly exposing virgin metal to the attack from the feedwater.

Thus, if the original pump capacity is liberally selected, there may be no indication that anything is wrong until such time that deterioration of metal has progressed to the point that the original margin has been "eaten up." The resulting breakdown immediately assumes the proportions of an emergency, since the net available capacity is no longer sufficient to feed the boiler. Unless additional spare equipment is available, the power plant operator may find himself in an unenviable spot.

Some years ago, one of the most startling cases of this nature came to my attention. When excessive internal leakage was discovered, the pumps could no longer carry the boiler load even with the help of the standby turbine driven pump. On dismantling, it was found that the wearing rings which were made of cast iron had corroded to a fantastic extent. The original clearances of 0.012 in. had increased to over 1/4 in. Other clearances had deteriorated in about the same proportion. The net capacity of the pumps (originally 300,000 lb/hr.) had fallen off to less than 200,000 lb/hr. The breakdown imposed a very serious emergency condition on the power plant, because no replacement parts were on hand. The reason for the unexpected nature of the trouble was that the maximum load on the boiler had seldom exceeded 650,000 lb/hr and generally hovered around 450,000 lb/hr. And yet three pumps were always kept on the line, each of these pumps carrying from 150,000 to 220,000 lb/hr load.

In order to avoid such an unforeseen emergency, it is recommended that complete tests of the pump performance be carried out at say not less than 3 months intervals, if the pump is built of materials which may be subject to corrosion-erosion attack. From a more constructive point of view, it is wise to investigate the effect of the feedwater used on the materials in the pump in question. If any indication exists that these materials may be inadequate, replacement parts of stainless steel should be ordered. If it is only intended to replace the internal parts by stainless steel and to retain the original cast iron casing, the replacement program should be carried out at the first opportunity rather than waiting to the end of the useful life of the original parts. Otherwise, the deterioration of parts which form a fit with the casing may lead to internal leakage which, in turn, will destroy casing fits and make repairs extremely costly.

But whatever your decision is as to the internal parts of the pumps you contemplate to purchase, I earnestly recommend that you *do not* specify cast steel casings. Too many sad experiences have been traced to its use.

Nineteenth Annual Water Conference

THE Nineteenth Annual Water Conference sponsored by the Engineers' Society of Western Pennsylvania originally scheduled for October 27–29, 1958, was postponed because of the hotel strike in Pittsburgh, and then took place December 8–10, 1958, at its usual site, the Penn-Sheraton in Pittsburgh. Attendance was close to the 500 average of the last several years. Below we present abstracts of the papers we hold to be of interest to the COMBUSTION reader.

Sewage Effluent

Sewage plant effluent can be used satisfactorily in recirculating cooling systems and as boiler makeup provided you treat it adequately, according to **J. E. Tarman** and **James H. Richards,** Betz Laboratories, Inc., in their paper, "Problems in the Use of Sewage Plang Effluent for Boiler and Cooling Purposes." The treatment is aimed at preventing operating problems from organic growths, deposits and corrosion in cooling systems and foaming, carryover and ammonia corrosion in boiler and steam systems.

Proper treatment including preparation and aftertreatment of the system using it can be expensive and complicated and hence tends to be uneconomical if adequate fuel water can be found. Cost figures were supplied to substantiate the authors' contentions. Further, some elaboration of typical problems from inadequate treatment was advanced.

C. Robert Johnson, Universal Oil Products Co., who expressed an essential agreement with the Tarman-Richards conclusions, added the risks of a sudden halt in the sewage plant, if municipally run, because of political or local pressures outside the control of any industrial that might be tempted to use the sewage effluent. Further the health aspect must be reckoned with. Many sewage plants become heavily overloaded and plant equipment is not improved. Cross connections have been known to be opened whereby potable supplies were tainted.

J. L. Hellman, Bethlehem Steel Co., recalled the experiences of his company's Sparrows Point plant where they employ a quantity of sewage effluent from the City of Baltimore. In 1952 the City improved its sewage handling facilities and results at Sparrows Point reflected this improvement. A number of tests were run on the value of alum as a treatment for effluent. The value was established but the cost was held to be too high and with waters of turbidities about 9 ppm or so it was not used. This is now the case at Baltimore, and Bethlehem Steel uses continuous chlorination at a rate of 5 ppm for algae and slime control so the Steel Co. costs are not at all unreasonable.

Frank R. Riley, American Cyanamid Co., similarly shared the sentiments of preference for fresh water over sewage effluent. He suggested certain specific applications increasing in quality requirements as the best utilization of what he felt to be an inferior water of unpredictable treatment costs. He noted the only users of record were plants demanding large quantities of water and suffering because of location from good water supplies.

L. P. White, Brown & Root, Inc., pointed out that use of sewage effluent is for one of these reasons: (1) insufficient fresh water available for industrial demand; (2) a desire to reduce the pollution load on receiving bodies of water; (3) conservation of available water, whether surface or ground. Any of these points and especially a combination can make what otherwise is an admittedly expensive source of water become attractive. Necessity, rather than economics, is the quick rule on the advisability of sewage effluent for industrial water needs.

Polymetallic Cooling System Treatment

E. H. Hurst, National Aluminate Co., pointed out in his paper "Water Treatment for Polymetallic Cooling Systems" that today the design of cooling water systems uses many different metals or metal alloys. If the metals employed fall within a similar group as measured by the Galvanic Series, problems will not arise from this cause. If not, and this is frequently the case, serious galvanic corrosion can develop from polymetallic couplings. The authors showed tables of materials according to their Galvanic Series and tabulated the metal's functional use such as carrying lines, heat exchange tubing or water boxes in a cooling system.

Further complicating the problem is the fact that a cooling system may use a number of different heat exchanger vessels and the polymetallic coupling possibilities increase proportionately. Mr. Hurst then discussed the various inhibitors available and also mentioned the employment of metallic coatings or cladding devices plus organic materials such as paint, epoxy, resins.

J. D. Minford, Aluminum Co. of America, felt that the approach to treatment of this galvanic corrosion problem by grouping metals with similar galvanic potentials was a good way to systematize data. He then discussed cer-

tain specific points in the Hurst paper as he felt they would influence aluminum. As an example Mr. Minford said the possibility that only boron or nitrate can give excellent results for systems containing copper, steel and aluminum seemed unlikely to him. These chemicals plus certain others, however, certainly could fit the description of excellent results for five years in one instance of his knowledge even with the presence of galvanic cells.

T. J. Hodan, Allis-Chalmers Mfg. Co., singled out the Hurst paper's admonition of the dangers inherent in acid cleaning heat exchange equipment unless care is taken to remove metallic ions such as copper which would otherwise plate out at various points in the cooling system and set up new galvanic cells. Mr. Hodan then reported on a two-year case history of a surface condenser in a nuclear power system employing aluminum tubes and steel tube sheets with a polyphosphate as the original basic corrosion control material. The first eight to ten months left much to be desired. Treatment was modified by adding a small amount of a complexing or chelating agent to prevent copper, especially, from going into solutions. When last checked, sixty days ago, after a six-month period, condition of the heat exchanger tubing was excellent.

W. A. Tanzola, Betz Laboratories, Inc., commented that Table 2 of the Hurst paper offered the key to polymetallic corrosion problems. This table outlined six factors accelerating corrosion and seven that served to decelerate corrosion. The procedures to employ in building or designing a new system are the ones that were dictated by the accelerating factors in the Hurst table. Once a system is in and working obviously the only thing that can be done then is to put to use the available knowledge of enhancing the decelerating factors. The knowledge is available for both and at costs Mr. Tanzola held to be reasonably economic.

Fundamental Corrosion Studies

M. M. Obrecht and **L. L. Quill,** Michigan State University, in their paper "Design of Tests Systems for Studying the Corrosion of Copper and Copper Alloys by Various Types of Water," began with the statement that for many years copper and copper alloys had been used in heat exchange systems and in hot and cold water distribution systems because they were reported to have excellent corrosion resistance over wide ranges of temperature, velocity and types of water. The study the authors gave here was the result of first hand experiences at Michigan State.

Here, following World War II a large building program was carried out using phosphorous, deoxidized, type L copper tubing for water distribution. About 1950, leaks developed, mostly in the hot water lines but also strongly evident in the cold. Oddly, the tubing installed before World War II in the older building was not at all rapid.

For the hot water system, a sodium zeolite softening is used and has been since the World War II construction. The older buildings now use this treated water but originally did not have treated water, and tube samples showed a protective coat had been formed by this untreated water. The failures could have been from aggressive water, at too high a temperature and too high a velocity. The heat exchangers also developed leaks of their own and it was decided to reduce flow rates and correct the aggressive water. Temperatures were felt necessary and so no temperature change was involved. Steps were taken to accumulate data on these factors and some of the data compiled make up this paper.

As an example of the findings the authors report it desirable to (1) lower water temperatures to 140 F, (2) blend soft and hard waters to give a slight positive Langelier index, (3) improve and control regeneration procedures for zeolite softeners especially in rinsing away residual chlorides, (4) control CO_2 content of water, (5) attempt to reduce O_2 concentration.

J. F. Wilkes, Dearborn Chemical Co., had previewed the background of Michigan State corrosion problems and believed them to be from underdesign and inadequate provision for increased flow demands. Specific data on adverse effects of dissolved oxygen, CO_2 and low hardness in softened systems should be forthcoming and will be most valuable. Possibly the addition of the soluble silicates might be worth investigation. Mr. Wilkes felt the pilot-plant studies now under way should supply information conspicuously absent from the technical literature. Comprehensive flow rate limits for copper and copper alloys as a function of temperature and water qualities are to be hoped for from these MSU studies.

J. M. Keyes, Calumet and Hecla, saw as the only major drawback to the authors' test set-up its high costs to furnish the quantities of heated water desired. Scaling down the tube size, Mr. Keyes observed, with the same relative conditions of velocity and temperature should reduce the costs. Further the test system represents very severe service conditions since the water is made to flow continuously with no rest periods. These rest periods that occur in practice allow protective filming to form on the tubes. As to the actual leaks at MSU the reasons were probably insufficient design time to take care of peak loads and avoid excessive velocities which are beyond those recommended by industry for copper.

C. L. Bulow, Bridgeport Brass Co., applauded the authors for their decision to use NDHA-ASTM test coupons for monitoring the system. It should establish their value in spotting corrosive conditions or tendencies and allowing remedial steps to be taken before a system is too badly damaged. Mr. Bulow took Graphs One through Four from the Obrecht-Quill paper and summarized them in two graphs, one for copper, one for red brass using velocity and temperature as coordinates. From these new graphs he felt it was easy to see the dynamic or pulsating nature of the corrosion in these tubes. The interplay of various reactions such as film solubility could also be observed. The test program of Quill and Obrecht, will, it is believed, become a classic in the field of corrosion engineering.

High Speed Demineralization

"Experiences with the High Rate of Flow Demineralization" was offered by **I. B. Dick** and **P. L. Silliman,** Consolidated Edison Co. of New York. The decision to build a large pressurized water reactor for the generation of electricity has required an entire readjustment of thinking of water purity and quality, according to the

authors. Whereas "million-ohm" water has always been regarded as a good boiler feedwater in conventional units, it may not be good enough for a stainless steel nuclear boiler. Two most objectionable components, chlorides and caustic alkalinity, could concentrate even from million-ohm water to a dangerous extent.

The only means of condensate purification available is complete demineralization and at Indian Point, dealing with some two million pounds an hour, a mixed-bed demineralizer installation of at least five 11-ft diameter units would be needed, operating at the conventional rate of 10 gpm per sq ft. The installed cost is considerable, and if related to a single unit steam generator would represent an appreciable percentage of the total plant cost.

With very high-quality condensate possibly occasionally contaminated with very small amounts of saline water, operation at through-put rates in excess of "conventional" seemed in order. The selected rates were 100 gpm per sq ft.

A cooperative agreement was entered into with the Illinois Water Treatment Co. to run a pilot-plant test in apparatus of sufficient size to give results directly applicable to plant design. A 20-in. diameter (2-sq ft) unit was furnished by Illinois and was installed at the Astoria Plant of the Consolidated Edison Co. on main condensate from No. 1 condenser.

From certain test results the authors believed they could state that: (1) Flow rates of 100 gpm per sq ft are feasible and that regeneration in place is feasible. (2) Water of extremely high quality is obtained, and this quality is not affected by the incidental condenser leaks encountered in normal operations. (3) High-flow, mixed-bed demineralizers can be regenerated in place successfully. (4) Capacity of the resins for this operation is more than ample.

A word of caution seems in order, the authors claimed. A high flow rate demineralizer to take full condensate flow from the condenser must not be regarded as a means of holding a badly leaking condenser on the line indefinitely. It is a means of keeping a condenser with nominal leakage on line until the earliest possible outage time, or a more seriously leaking condenser on line long enough to effect an orderly shutdown.

The continuous by-pass demineralization of five per cent of the total condensate has improved water quality, and has reduced copper and iron values in feedwater to about the same extent as a filming amine in an identical boiler.

W. J. Singley, Bettis Div., Westinghouse Elec. Corp., believed the paper to be a valuable contribution to the elimination of possible stress corrosion problems in stainless steel steam generators. Condenser leakage is the major source of chloride contamination and condensate demineralization is its only feasible treatment. The authors' demonstration of a high quality water in a 20-in. diam pilot-plant column is a significant advance in the application of full flow condensate demineralization. But caustic stress corrosion must not be ignored. A proper phosphate-pH balance can achieve protection from this stress.

A. C. Reents, Illinois Water Treatment Co., saluted the Dick-Sillman paper for its contributions to the industry's knowledge. He then concentrated on the pressure drop problems through the resin bed. The authors' solution—larger resin beads—he felt reacted against the quality of the effluent. Iron and copper removal was not as good, for example. Further, the large beads reduced exchange capacity. It might be desirable then to live with a high pressure drop but obtain better mechanical filtration with the smaller beads. Mr. Reents volunteered some data on high flow rate studies with a water of higher salt concentration than that used by Dick-Sillman.

M. E. Gilwood, Permutit Co., emphasized the difficulties of the Dick-Sillman conditions of operations, namely continuous operation at 100 gpm per sq ft and no prior filtration to remove colloidal iron or copper. Mr. Gilwood recounted his company's pilot-plant test experiences with demineralized water in a recirculated closed loop at 50 gpm per sq ft. From a comparison of test data Mr. Gilwood recommends a 50-gpm-per-sq-ft operating rate with some prefiltration.

New Ion Exchange Techniques

H. W. Frazer, Infilco, Inc., in his paper "Special Operating and Regenerating Techniques for Ion Exchange" described the evolution of ion exchange plants for water treatment and the typical specifications determining the size of equipment to be used today. The fundamental factors affecting modern ion exchange materials came in for discussion.

The processes and equipment details have improved during the past 20 years but basic plant design, the author felt, had not. In his review of modern materials and techniques he made certain suggested changes which he believed would result in a reduction of equipment costs.

For example, under flow rate, Mr. Frazer stated, usual specifications limit rate of flow to between 6 and 10 gpm per sq ft. Commercial units are now available operating at flow rates as high as 21 gpm per sq ft. These advances should be reflected in the usual set of specifications offered to a prospective buyer.

In a similar vein such subjects as bed depth and regeneration per day were covered and then certain suggested plant designs utilizing these advances were presented.

M. M. Baker, Commonwealth Edison Co., in discussing the Frazer paper said. "We do not have the time nor the research facilities to become experts in the field of development of ion exchange. We should rather rely on the manufacturer." Tests from the manufacturer's pilot plants indicate the new materials, the new ideas and equipment the user will buy and support in initial installations. Manufacturers should strive to standardize where they may. Such standardization results in lower costs and increased sales.

J. W. Strub, E. I. du Pont de Nemours & Co., felt the Frazer proposal allowed taking full advantage of both resin capacity and flow characteristics of ion exchange materials and permits designing an operating unit for a single function. A similar result can be achieved for the regenerating equipment and thus avoid the problems of dual function and comprised design for a single unit.

B. N. Dickinson, Chemical Process Co., agreed with the Frazer comment that flow rates and overall performance of ion exchange plants can be stepped up. He cited certain experiences of his own company and the corroborating evidence they uncovered.

M. E. Gilwood, Permutit Co., echoed the sentiments of the other discussors and agreed with the Frazer contention. He questioned, however, the externally regenerated ion exchange arragement portrayed by Mr. Frazer in his suggested plant design. Gilwood believed a conventional "regenerated in place" ion exchange plant of a size to meet the Frazer suggested one would cost 25 per cent less than Frazer's transferred resin type installation.

Handling and Feeding Chemicals

A full afternoon was given over to a panel on handling and feeding chemicals to water treating equipment. The panel members broke down the general subject into five categories and made their contributions as follows:

(1) "Handling and Feeding Acid to Demineralizers" by **T. P. Harding,** Omaha Public Power District

(2) "Handling and Feeding Caustic Soda to Demineralizers" by **Ivan S. St. John,** E. I. du Pont de Nemours & Co.

(3) "Handling and Disposal of Water Treatment Wastes by **E. G. Paulson,** Hall Laboratories Div., Hagan Chemical and Controls, Inc.

(4) "Handling and Feeding Chemical Solutions to Clarifying and Softening Equipment" by **J. E. Starry,** National Aluminate Corp.

(5) "Handling and Feeding Dry Chemicals to Clarifying and Softening Equipment" by **J. F. Wilkes,** Dearborn Chemical Co.

The individual papers were all good, detailed and undoubtedly a primer on this subject. Since the papers are largely compilations of proved safe practices and since the Engineers Society will publish the proceedings in full we shall not attempt a paper-by-paper abstract.

Field Testing Ion Exchange

"Field Testing of Ion Exchange Materials" by **F. X. McGarvey, R. Kunin** and **N. Frisch,** Rohm & Haas Co., described an attempt at obtaining field data on ion exchange materials. Borrowing from corrosion testing procedures an analogous arrangement of a basket container was devised. A small sample of exchanger is placed in a screened basket and the basket is suspended in the bed of an existing and operating commercial ion exchange installation. Samples of the resin are periodically withdrawn and evaluated by standard test procedures. The technique is described quite fully and has been tried for both anion and cation resins in many installations. Then the results from the on-spot tests were compared with the same resin contained in the bed proper surrounding the basket. Data comparisons to date were held to be most encouraging.

G. J. Crits, Cochrane Corp., accepted the idea that this "basket testing technique" enabled a side-by-side study of many different ion exchange resins under field conditions but he held that it suffered because of the drawbacks inherent in any accelerated test. These drawbacks as Mr. Crits saw them were: (1) each basket is fed by an undetermined quantity of water which it would appear is a function of the basket design and the manner of its installation, (2) the resin samples in the baskets may be exhausted in the first few hours of operation of the large unit. Therefore the resins are being contacted by large volumes of water in the exhausted state. On the other hand, the basket samples may be regenerated with many times the normal amount of regenerant.

R. J. Cooley, Chemical Process Co., saw the technique as an intermediary step between accelerated bench scale testing and pilot plant evaluation. His suggestion was to place all the resins involved in baskets to achieve truly parallel results. There is always a question, he felt, as to whether a confined resin is undergoing the same ion exchange experiences as the outside free bed. In parallel experiments location of the baskets is of little importance as long as all are placed essentially in the same zone.

Understanding Ion Exchange

L. F. Wirth and **A. M. Fradkin,** National Aluminate Corp., in their paper, "Developments in the Understanding of Ion Exchange" stressed that much of the excellent progress in the practical applications of ion exchange resins has been prompted by a willingness to meet the problems. As an example the authors cite the advent of higher cross-linked cation exchanger for certain oxidizing conditions causing degradation of the standard resins.

The paper devoted itself to brief recounts of various other developments. The styrene resin story was featured. Some mention was made of the problems the nuclear field and supercritical boiler pressures were creating. The authors urged that out of all these studies a correlation of field observations with laboratory techniques should be emphasized.

Russian Practices

"Russian and Eastern European Water Treatment Practices" was presented by **V. J. Calise** and **W. A. Homer,** Graver Water Conditioning Co. This paper is the result of an attempt to survey water treatment practices in Russia and East Europe. In preparing this paper, the authors had available four sources of information:

(a) The technical literature from Russian periodicals almost all of which required original translation and review for preparation of this paper. More than 150 literature references were reviewed, of which approximately 30 technical articles were translated into English.

(b) Information from American and other visitors to Russia such as Andrew Kramer, editor of *Atomics, Power Engineering*; Shelton Fisher, publisher of *Power*; British electric power engineers' report on their visit in 1957, and others.

(c) Information directly from Russian experts and

authorities in this field. Direct communication was established with A. Pavlenko, Soviet Minister of Power who visited Montreal, Canada, in September 1958 for the Canadian World Power Conference.

(d) Personal visit to Russia originally scheduled in time for this conference but delayed due to press of other business.

However, the technical literature and reports from visitors to Russia provided the main sources of information. Although excellent cooperation was received from Soviet authorities when preparing questions to be answered by technical experts in the USSR, this information was not received in time for this paper.

In summary, it should be made clear that Russian feedwater treatment practices in the past have been influenced a great deal by German and West European practice. As W. Cerna pointed out in his paper in 1947 such practices involved use of multi-drum, multistage evaporators with so-called steam transformers to maintain the purity of feedwater to the primary boiler drum, starting off with generally poorer quality makeup. The consequence of this has been for Russian and German power plant engineers and designers to accept considerably increased first costs in order to make certain of high feedwater purity and steam purity at key points in the cycle, notwithstanding the generally poor quality of makeup water supplied to the cycle.

The recent introduction of ion exchange demineralization of the relatively high per cent makeup (5-10 per cent vs. 0.5-1 per cent U. S.) will probably alter Russian thinking in use of multi-stage evaporation units and will probably reduce first costs in power plant design. Condensate scavenging has not been at all practiced or worked upon to any degree in Russia. Further, there is evidence of multi-bed train unit operation (up to 7 units in series) on demineralizers for makeup treatment but no work at all on mixed-bed demineralizers. The authors point out that nowhere have they seen a better illustration of the contribution that could be made by progressive water treatment engineering designers and power plant chemists, experienced in the latest processes and techniques of ion exchange practices.

The absence of a firm, well-informed power plant chemists fraternity such as the EEI, ASME, Joint Research and ASTM groups to set up standards of equipment performance and operation is clearly visible in the scattered operating data available in the literature. The authors then commented on general industrial water treatment practices, municipal water treatment, and gave a breakdown of treatment practices by process and equipment.

As an example of the coverage the authors give we quote: "In the area of deaerator design and performance, Russian practice indicates a sad lack of appreciation of the need for oxygen reduction to values under 0.005 ml liter in view of their many other water treating problems. The amazing variety and versatility of American deaerating heater designs (spray, tray, spray tray, atomizing, bootstrap and cascade) and practices in central station plants and industrial plants, is nowhere found in Russia, East or West Europe or elsewhere in the world.

"Water spray unit and distribution unit designs appear to be limited in form and conception. The concepts of lower partial pressures and free fall over many weirs and edges in a pure steam atmosphere, so effectively employed in tray and spray tray heaters in the U.S.A., is not found in Europe and Russia.

"Despite the widespread use of thermal deaeration and the dependence of high pressure boilers on oxygen-free water, no major research in deaeration or testing of current designs took place in Russia until 1953-1955."

Pipeline Transportation Held a Certain "Comer"

Industry, aided by research, will find increasing use for pipelines engineered to carry solid particles mixed with air or water. This is the prediction of Edward P. Ballinger, a mechanical engineer at Battelle Memorial Institute, in an article on "solid-fluid" transport appearing in the October issue of the *Battelle Technical Review*. Materials which have already been moved in liquid mixtures have included coal, grain, sand, drilling muds, and salad dressing, according to the specialist at the Columbus, Ohio, research center. Conveyed in gaseous mixtures have been pulverized coal, powdered cement, grain, wood shavings, cinders, sand, small rocks.

Chemical and petroleum industries have been the most frequent users of solid-fluid conveying, Ballinger observes. Distances involved have usually been less than a few thousand feet, but two examples involve miles of pipeline. About 700 tons a day of gilsonite, an asphalt-like mineral, is moved 72 miles by pipleine from a mine at Bonanza, Utah, to a plant near Grand Junction, Colorado. The mineral is pulverized and mixed with water, as is coal for a 108-mile pipeline from mines near Cadiz, Ohio, to an Eastlake, Ohio, plant.

The petroleum industry, to transport catalysts, introduced the use of gaseous mixtures with dense solids. Ballinger uses the term "dense-phase conveying" to include mixtures with ratios of 100 parts solids to one part air, by weight. Ratios may run as high as 5000 to one, and delivery of 200 tons of material an hour is not unusual. Numerous systems are also being used for low-density mixtures with up to 20-to-one ratios of solid matter to air. A main advantage of pneumatic transport is the absence of moving parts, Ballinger notes, although abrasive solids can erode the walls of the pipes containing them.

There are no "elegant, theoretical" solutions to design problems for pneumatic transport, says the Battelle engineer, but investigators have found a number of important factors governing results. These include the velocity, density, and viscosity of the transporting medium; size, shape, density, and roughness of the particles; and diameter and roughness of the conduit. Particles may progress with a bouncing action, colliding with conduit walls and rebounding, or they may be suspended in the flow of gas. Motions of extremely small particles are affected by collision with air molecules.

Many attempts have been made to obtain a general equation for the loss of pressure inside a pneumatic transport conduit, writes Ballinger.

ASME Annual Meeting Highlights—II

Last month COMBUSTION reported on the Annual Meeting of the ASME held at the Hotel Statler and the Hotel Sheraton-McAlpin New York City the week of December 1-6. The following papers are abstracts from that same meeting which we did not carry before because of space limitations.

Corrosion Control

The need to know where we stand before launching any heavy control project prompted the paper "Gaps in our Knowledge on External Deposits and Corrosion in Boilers and Gas Turbines" by **Bertrand A. Landry,** Battelle Memorial Institute. The author's organization has recently completed a survey of the available information on external corrosion and deposits in boilers and gas turbines for the ASME Special Committee on Corrosion and Deposits From Combustion Gases. This paper is a part of the extensive report submitted to the Committee and stresses the areas wherein no literature or recorded information exists. The author poses many challenging questions in pointing up the gaps in our knowledge. For example, he queries if deposition is unavoidable, can the corrosive effect of deposits be reduced through the selection of metal surfaces? The field of new alloy development is so huge that there is every assurance that alloys can be found which will have the needed mechanical properties and corrosion resistance. The challenge here is one of cost; but the chances remain good, particularly for structural members that are not water or air cooled.

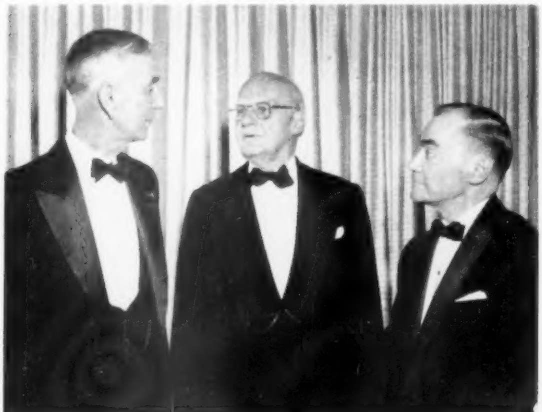
A promising area for corrosion resistance is that of metal surface coating. This cannot be said to have been successful, so far, in boiler or turbine applications, but so many techniques and so many types of coatings are now available that it would be surprising if none was successful. Effort in this direction would seem to be justified.

One aspect of the metallurgical problems associated with deposits and corrosion that must be kept in mind is that of the compatibility of additives to fuels with the metals that they may come in contact with.

Because boilers and turbines are normally poor ash collectors, there has been little hesitancy in the use of additives, to combat specific nuisances such as vanadium compounds and SO_3, because the boiler and turbine could be relied upon not to retain too much of the additive. However, this has not always been true, and certain additives, while reducing corrosion effects, have added to deposit problems. Special attention, through the use of the proper research equipment, should be given to the complete behavior of additives so as not to solve one problem at the expense of another.

Although the specific effect of additives seems to have been well explored, there is probably further research to be done in this direction. An important aspect of the use of additives is the method by which they are added to the fuel. For gas turbines, a possible approach is the development of oil-soluble additives for reaction with vanadium. However, these may be costly. The possibility of incorporating a water-soluble additive with the oil should not be overlooked if the additive can be shown to be equally effective. The presence of a certain amount of water solution in the fuel oil supplied to a gas turbine is beneficial to the cycle, if this water does not interfere with pumping, atomization, and combustion. This is not true of boiler-fired systems, but better distribution of the additive might be achieved in this way, at a slight thermal loss.

As to the introduction of fine solid additives in the gas stream of boiler furnaces, the art seems to be still in rela-



Reading from left to right, E. L. Robinson, General Electric Co., elected to honorary member, Howard Coonley, Walworth Co., also a new honorary member, and W. H. Armacost, Combustion Engineering, Inc., recipient of the ASME Medal

In the usual order O. B. Schier, secretary of the ASME, Philip Sporn, American Electric Power Co., and F. P. Fairchild, Public Service Electric and Gas Co., get together before the Fuels Division luncheon

tive infancy, and applied research will probably be required to smooth out this operation.

The author employs much the same handling in his treatment of acid in gas, the advantages of models and other areas of interest.

Still another paper in this general area of interest "Shot Cleaning—Its Development and Use for Cleaning Economizers, Tubular Air Heaters and Applicable Boiler Sections" was presented by **R. C. Chappell,** Diamond Power Specialty Corp. and **R. C. Meyer,** Philadelphia Electric Co. and appeared in full in December on pp. 39-45. Its subject matter falls within the scope of ways to remove corrosion or deposits from metallic surfaces.

Still another candidate in considering suggestions on corrosion control was the paper "A New Look at Specialized Refractories as Maintenance Tools" by **Roy W. Brown,** the Carborundum Co.

This study of super refractories for maintenance purposes is directed essentially toward the specific yet general problems of wear and corrosion. It is also concerned with product properties of thermal conductivity, abrasion resistance, hot strength, thermal shock, impact resistance, and chemical inertness.

These nonmetallics, Brown cautioned, should not be looked upon as a group of heat-resisting materials. Nor do they possess precise properties in the sense that a specific alloy is precise. Neither do they offer any panacea because drawbacks sometimes go hand-in-hand with their useful properties. Acceptance of these negative factors leads to a clearer understanding of the positive product qualities; diverse applications; range, complexity, and limitations of shape design; and subordination of heat resistance to other characteristics.

The nonmetallics covered herein provide a far greater range of thermal conductivity—from insulation to conduction—than any other class of material.

While cast iron and alloy steels are exceptional heat conductors, this ability decreases as temperatures rise. Moreover, use limit is approximately 1500 F. Ceramic-bonded silicon carbide, usable to about 3000 F, has a conductivity that is virtually a straight-line curve from 105 Btu per hr per sq ft and deg F per in. of thickness at 1000 F to 112 Btu at 2900 F. A rough measure is about eleven times that of fireclay and 70 per cent that of the chrome-nickel steels.

Where slag accumulates on boiler-tube facing, it reduces efficiency and, under certain conditions, attacks the facing. Fireclay doubtless would resist attack, but with its low heat conductivity actually insulates the tubes. A high conductive silicon-carbide facing decreases the possibility of reaction and gives maximum heat flow. Any slag that might adhere can be barred off with ease.

There are instances in industry where moderate to high temperatures are the only problem. A conventional natural-gas-fired boiler is illustrative. For the most part, however, high temperatures inevitably are coupled with molten slags, metals and fluxes, and corrosive fumes.

Specialized refractories, as a general class, are far more resistant to these types of corrosion than are the refractories made from Nature's raw materials. This greater resistance is imparted largely by the crystalline grog; crystals are formed at extraordinary temperatures lessening any tendency to change shape or go through a conversion phase at lower temperatures.

Water Treatment

In the medical sciences, **Douglas E. Noll,** Hall Laboratories, reported there is a subdivision called "geriatrics" which is concerned with the diseases of old age in humans. In the title of this paper, "Thermiatrics, the Diseases of High-Temperature Boilers" there appears a coined word "thermiatrics" which Noll defines as the study of the afflictions of boilers operating at high temperatures. It was used here because its analogy to geriatrics help introduce the subject.

The term "high temperature" is used advisedly because it is the factor that is particularly significant in most of the developments that lead to tube failures in high-pressure, central station boilers. The disease of high-temperature boilers are those associated with the formation of iron oxide in areas of high heat transfer.

In an operating boiler between the furnace gases and the bulk of the boiler water, there is a temperature difference on the order of 2000 F which produces a flow of heat through the tube wall. After the boiler is put in operation and the oxide layer begins to grow the share of the temperature drop taken by the oxide must steadily increase with a corresponding increase in the temperature of the tube metal. The hotter the metal becomes, the faster it will build upon the oxide layer on its inner surface in contact with the steam-water mixture as well as upon that on its outer surface in contact with the furnace gases.

Fortunately, except for a few critical locations in a relatively small percentage of high-pressure boilers, the oxide film on the inner surface of the tubes apparently remains a more effective barrier to the migration of iron than it is to heat transfer. Those extreme cases of overheating which result in metal creep, regardless of conditions on the inner surface of the tubes, are outside this discussion. The critical range of temperature generally not exceeding 1000 F requires attention. It would certainly be a great stride forward, the author contended, if it were possible to define the conditions that cause the oxidation process to "go critical."

C. M. Loucks, Dowell Div., Dow Chemical Co., **E. B. Morris,** American Electric Power Service Corp., and **E. A. Pirsh,** The Babcock and Wilcox Co., presented the valuable story of "Organic Acids for Cleaning Power-Plant Equipment." The organic acids which have been of particular interest for cleaning operations are those in crystalline solid form which may be packaged with ease and used with the minimum of danger to the user and the equipment. Oxalic, citric, and tartaric acid, and the acid salts such as sodium and ammonium-acid citrates are well-known agents for dissolving rust and scale. Crystalline inorganic acids and acid salts such as sulfamic acid and sodium acid sulfate, for example, also have been used for the same purposes. For large-scale operations, involving power-plant equipment, inhibited hydrochloric acid is widely used. It is readily available at low cost and is suitable for most cases.

The need for cleaning surfaces was recognized in the early design stages of the supercritical-pressure steam generator for Unit 6 at Philo. However, the available building space predicated a design which prevents complete drainability. Also, the final superheat temperature of 1150 F necessitated the use of austenitic material in the secondary superheater. These two factors required a strict appraisal as to the suitability of hydrochloric acid for the cleaning of this steam generator. It was concluded that the design permitted acid to be introduced into and removed from all the regions of the steam generator which would require cleaning. Further, that the fear of the effect of hydrochloric acid on the austenitic material could be eliminated by maintaining the secondary superheater full of condensate and utilizing the superheater bypass as a solvent return line. Despite these conclusions, it was recognized that other acids might be available which would offer a greater degree of safety in the event of some unforseen incident during the cleaning and rinsing operations. Accordingly it was decided to investigate other acids. Sulfuric acid was rejected since the commercial inhibitors available did not provide sufficiently low corrosion rates for all the alloys involved. Thinking then proceeded toward the organic acids.

Perhaps the most significant conclusion is the fact that for a special chemical-cleaning situation organic acids have been used successfully. The less expensive mineral acids undoubtedly will remain the "work horses" of chemical cleaning maintenance service.

The whole field of the use of chemical solvents for large-scale maintenance operations is in its infancy. To the chemist and the chemical engineer it is a relatively new special field and it is full of challenging problems and opportunities. Much work needs to be done with just the two acids discussed in the paper. The chemistry of citric acid and ammonium citrate needs further investigation. Preliminary trials with addition of hydrazine citrate, which is a reducing agent, have shown interesting possibilities. Also, the properties and conditions of use of formic acid need further attention. Perhaps formic acid could be used in low-pressure steam as a cleaning medium. This possibility is being investigated. And dozens of other materials; acids, alkalies, reducing agents, oxidizing agents, chelating agents, surface active agents, inorganic and organic salts are some of the types of substances that offer interesting properties to the investigator.

I. B. Dick and **P. C. Fritz,** Consolidated Edison Co., collaborated in the report "Experiences With Cyclohexylamine in the Condensate-Feedwater Systems of High-Pressure Boilers." Five years of experience with cyclohexylamine in two 900-psi boilers, over a year in two 1750-psi boilers and about 6 months (at time of writing) in a 2020-psi boiler are reported. Within the past 2 years, some improvement in cleanliness in the 900-psi units seems discernible, but to date is not conspicuous. Deposits removed from wall tubes by turbining have decreased materially. Iron and copper concentrations in feedwater have been reduced to low values. Some improvement in heater cleanliness is attributed to the amine treatment. Conclusions are that cyclohexylamine treatment imposed on boilers after a period of several years of operation did reduce iron and copper concentrations in feedwater within 6 months; that visually improved boiler cleanliness did not appear for 3 years and is not pronounced even after 5 years; that some improvement in feedwater-heater cleanliness may be expected; that no harmful results have been experienced; that cost is very small; and that, all factors being considered, the treatment should be continued.

During the period that amine treatment has been in use at the Arthur Kill Station, routine tests for ammonia have been made at the various locations in the feedwater cycle. Except for the high concentrations that occurred while the vent condenser on the deaerator was out of service, the ammonia concentrations have been essentially zero at all sampling points with occasional values occurring up to 0.04 ppm at the deaerator storage tank and bleed heater pumps, and up to 0.06 ppm at the reclaim tank. Since the retubing of the vent condenser, ammonia concentrations have been zero. On the basis of these tests, cyclohexylamine appears to be stable under conditions prevailing at this station.

Routine tests have been made at the superheater outlets of the two 1750-psi boilers since the amine treatment was introduced and the results show concentrations ranging from 0.30 to 0.60 ppm. A few tests have been made recently at the aftercooler of the evactor system associated with the 2020-psi boiler and ammonia concentrations have been obtained ranging from 0.20 to 0.40 ppm.

G. L. Hopps, M. E. Getz, and **A. A. Berk,** Bureau of Mines, described "Trace Concentrations of Octadecylamine and Some of Its Degradation Products." The use of octadecylamine in Federal heating systems as a filming treatment to control return-line corrosion has been indifferently successful in comparison with results reported by industry. This paper reports the initial testing toward developing basic information on the filming treatment with the object of improving its effectiveness. The problem was complicated by the disclosure that octadecylamine is unstable in a heating system, the principal degradation products being dioctadecylamine and ammonia. Three analytical procedures are described as used in the survey testing. A bromophenol blue colorimetric procedure determines amine nitrogen in both octadecylamine and dioctadecylamine. The secondary and primary amines are differentiated by two nonaqueous titrations, for one of which the primary amine is sequestered by low-temperature reaction with salicyladehyde. Ammonia is determined colorimetrically by a phenolate procedure that does not develop the turbidity so frequently encountered in nesslerization.

As for plant experience, the first and most complete survey was made in a plant operated at 100 psig, with an average daily steam load of 670,000 lb. The average daily makeup was only about 2 per cent and the makeup was essentially ammonia-free, so that conditions were very favorable for observing the effects of increasing and decreasing octadecylamine dosage on the ammonia content of the steam and condensate. After 3 months of continuous injection into the export steam of an average dosage of about 1 ppm, the ammonia concentration ranged between 1.5 and 2 ppm. A subsequent increase in octadecylamine dosage resulted in a corresponding increase of ammonia in the system and the trend was reversed when the dosage was decreased.

N. L. Dickinson, W. A. Keilbaugh, and **F. J. Pocock,** The Babcock & Wilcox Co., offered as their paper, "Some Physico-Chemical Phenomena in Supercritical Water." There has been a continued demand on the part of the electric utilities for lower station heat rates. The knowledge that increased cycle efficiency could best be obtained by increasing the operating pressure and temperature, led into an intensive study of the problems involved in generating steam at supercritical pressures. Both European and past experience indicated that proper water conditioning and control would constitute the basic criteria for successful continuous operation of a once-through supercritical unit, since most of the impurities in the feedwater would be available for deposition within the steam generator and the turbine. To investigate the feedwater-purity requirements for units of this type, a pilot plant was constructed at the authors' company research center in 1952. During the operation of this test unit under varying conditions for the past 6 years, several phenomena were observed. Two of the more interesting of these phenomena are the subject of this paper. Test operation with regard to waterside deposition is summarized briefly and a theory presented to explain the location of some of these deposits. In addition, data are presented which show the partial dissociation of water when throttling for sampling from high pressures.

Satisfactory once-through supercritical boiler availability was obtained using commercially feasible water treatment methods. Since the possibility of improper water conditions and their resultant effect on long term operation must be considered, an investigation was made to study this effect.

As a result of this investigation, a theory with supporting data has been presented explaining the location of feedwater contaminant deposition in the critical region. The theory states that the line of constant specific volume (critical isochore) which passes through the critical point of a P-T diagram divides the supercritical region into areas of liquid-like and gas-like properties, and that deposition occurs at the loci of points defined by the critical isochore.

The use of valves for throttling samples from high pressures was found to produce dissociation of water. This phenomenon can lead to errors in determining the true values of oxygen and hydrogen and should be considered when designing sampling systems.

H. R. Lawrence and **R. J. Ziobro,** Griscom-Russell Co., presented a paper entitled "An Evaporator Vapor Purity Test Using the Sodium Tracer Technique." The results have shown that evaporator vapor may be produced containing less than 10 parts per billion total dissolved solids over a wide range of vapor flows. It has also been shown that a maximum level increase of 5 in. (which is more than adequate for displacement-type controllers) will not adversely affect the vapor purity if the splash baffle has been located properly. The results also have shown that excellent purity may be obtained without the use of a moisture separator although a simple centrifugal separator provides great protection against severe carryover during abnormal operation. The mesh-type separator, while of great interest in other industries, does not appear to offer sufficient advantages over the less expensive centrifugal separator to justify its use. In fact, the failure of the mesh to prevent severe carryover during abnormal operation would, in the authors' opinion, seriously limit the use of the mesh in high-purity applications. Normal turbine load changes have only a small effect of short duration and do not measurably increase hourly averages. The data also have shown that the use of a splash baffle effectively aids in reducing vapor-purity variations caused by changing turbine loads.

Other tests and field reports have shown that lower purities may be encountered during low-load operation. It is the authors' belief that fog generation is the most probable cause of lower vapor purities at low loads and that excellent purities at such loads can be obtained if the level controller is adjusted to keep the tube bundle completely submerged.

"One Utility's Experience with Filming Amines" was the subject of **John P. White,** Arkansas Power and Light Co. Briefly stated his company's experience with filming amines indicates that it is another tool to be used in boiler-feedwater system protection. In the station where it was first tried indications are that the system is well protected and the cost is somewhat less than through the use of other methods. Operation is certainly simpler. At the other stations sufficient time has not elapsed to give the final answer although it appears the results will be competitive with other treatments. To date the filming amine has given better protection from copper pickup than either neutralizing amines or no treatment. The filming amine in the 100-Mw unit has not proved quite as effective at eliminating iron pickup as the neutralizing amine but this may be due to insufficient time to clean out the condensate feedwater system completely. Even at the present stage of clean-up, iron pickups are much less than experienced with no treatment.

The use of filming amines is not without its problems. It has a cleaning action and a tendency to bind iron and copper oxides into a sticky substance on the low-temperature part of the system. This may not be a bad feature since usually this is the easiest portion of the system to clean, and this serves as a means to collect and remove these oxides from the cycle before they get into the boiler.

Flame Failure

Ross Forney of Forney Engineering Corp., speaking in the Flame Failure Symposium said in his talk, "Compatibility of Flame-Failure Equipment With Boiler Controls," that the thesis he wished to present is a simple one. Namely, if the manufacturer of flame-failure equipment, design engineer, construction superintendent, plant operator, and maintenance foreman each does his job properly, there will certainly be compatibility of flame-failure equipment with the boiler controls. Each member of this team is dependent on the other and each must carry his share of the load. Failure of one member spells ultimate dissatisfaction with the flame-failure device. In this area of power-plant operation, a mistake by one member is very difficult to compensate for by the other members.

No one will dispute the desirability of flame-failure

equipment, but experience to date indicates more thought and planning must go into its application. There are several stages at which the flame-failure system can be crippled to such a point its usefulness is compromised.

W. F. Lange and **John Dunn,** Peabody Engineering Corp., teamed to present "Application of Existing Flame-Protective Equipment to Oil and Gas Burners." They began with the observation that flame-protective devices presently are used as burner safeguards by scanning and proving pilot-igniter flame and main-burner flame. Much has been written covering the low-capacity, single and dual-burner application and the authors believed satisfactory performance in this category is a matter of record. This paper limited itself to the use of flame-protective equipment on multi-burner large central-station and industrial-boiler installations but did not discuss the design and circuitry of the devices themselves and covered only the photoconductive type of units the authors held as in most general use.

Their most pungent statement was: "There are many different ideas in regard to the function of flame-protective equipment; how it should be installed and its capabilities. One of the greatest needs of industry is a set of standards covering its installation and use, and stating just what such equipment can be expected to accomplish and what it cannot accomplish in way of protection.

"At the present time individual suppliers of control equipment, to a large degree, determine what is furnished to the user. It is true that there are certain insurance company tentative standards, but these seem to be deficient in many major respects and are interpreted differently in different geographical areas.

"One advantage of uniform standards will be that the supplier, who puts in all he feels is really desirable in the way of protective equipment, can point to these standards and will not so readily be penalized in competition with someone else who is less particular in regard to what he furnishes.

"At the present time the burner manufacturer who furnishes flame-protective equipment, must supply a custom engineered job in accordance with a specification often incomplete and with little hope that it will be fully effective. If it isn't, he is left 'holding the bag' on service and the expense incurred in making a job work to the intent rather than the written specification. Standards should not only cover the capabilities of the protective equipment and its use for various classifications of boilers and burner groupings, but also indicate responsibility areas in event of improper functioning.

"In the present state of the art, it does not appear that for multiburner high-capacity installations, available protective equipment can substitute for an inherently stable fuel burner and a vigilant supervising boiler-room operator. One of the biggest hazards in connection with the installation of flame-protective equipment, for multiburner, high-capacity jobs, is to assume that it can never fail to function properly and to place complete dependence upon it to the exclusion of proper operator supervision.

The success of any flame-protective application depends on periodic inspection of electronic components as well as a maintenance program for the mechanical equipment with particular reference to the fuel shut-off valves to insure positive shut-off on demand."

J. B. Smith, Factory Mutual Engineering Div., discussed the "Need for and Requirements of Flame-Protection Equipment for Gas—Oil—Pulverized Coal." As Mr. Smith stated, larger boilers and correspondingly more severe boiler-furnace fuel explosions, manual lighting-off by remote control, and automatic lighting-off are three current trends in large boiler installations, such as the public-utility type, which increase need for flame-failure protection equipment. Two criteria for direct and continuous measurement of the fuel-explosion hazard, utilizing instruments available today are (a) pressure or absence of normal flames, and (b) concentration of combustibles and oxygen in the flue gas

The conclusions of the author were: (1) Neither the flame-sensing nor the gas analyzer instrument available today satisfy our criterion of fuel explosion safety for large boilers to the needed degree for all fuels and all firing conditions. (2) He believed the most promising results would be realized from a combination of flame-sensing and gas-analyzer devices, with trip of total fuel to be activated only when both types of devices agree that the furnace is in serious danger. This is what he would recommend for flame failure protection for large boilers of the utility type. (3) Flame-sensing devices, capable of identifying individual lighters, and individual main burners, at low ratings, are recommended for boilers with remote or automatic lighting-off.

Pumps

The story of "Thermal and Economic Consideratons in the Application of Hydraulic Couplings for Boiler Feed-Pump Drives" was presented by **T. J. Whelan,** Stone and Webster Engineering Corp., to determine whether hydraulic couplings should be installed for variable-speed operation of boiler feed pumps, as compared to constant-speed operation, in steam-electric power station, the power saving obtained with variable-speed operation is often considered to be a major factor in justifying the additional investment for hydraulic couplings. This paper attempted to show that when the effects of constant and variable-speed operation on the feed-heating cycle are considered, and the present-worth value of the difference in predicted annual fuel costs is taken into account, the net power saving with variable-speed operation contributes comparatively little, if anything, toward the justification of additional initial investment for hydraulic couplings. The justification of additional initial investment for hydraulic couplings, therefore, rests principally on the expectation that maintenance costs will be reduced and the life of equipment extended.

The author advanced arguments that (1) the net power saving with variable-speed boiler feed pumps, driven through hydraulic couplings by constant-speed motors, as compared to constant-speed pumps, is appreciably less than the difference in motor-input requirements, and may even be a loss at or near maximum load; (2) the value of the resultant fuel savings is affected adversely by the nature of the usual steam-electric-station load-duration data. For turbine-generator units larger or smaller than the 180 Mw capability unit used in the example, or having initial steam pressures other than 2520 psig, the change in feed-pump efficiency and in the cycle efficiency from the boiler feed pump to the condenser would be small, and the relationship of

the net power saving to the maximum pump power requirements would be approximately the same.

Where the boiler feed pump is located higher in the feedwater cycle and handling hotter water, the increase in "excess" pump power required with constant-speed drive is offset by the fact that the excess power is utilized more efficiently in the cycle, so that the net power saving is approximately the same. In the same manner, with the feed pump located lower in the cycle and handling colder water, the decrease in excess power requirements is offset by the decrease in cycle efficiency from the feed pump to the condenser so that the net power saving is again approximately the same.

Mr. Whelan concluded, therefore, that the net power saving obtained with variable-speed boiler feed pumps driven through hydraulic couplings by constant-speed motors, as compared to constant-speed pumps and motors justifies comparatively little of the additional initial investment for variable-speed drive, particularly when a spare pump is installed, and that the justification of hydraulic couplings rests principally on the expectation that maintenance costs will be reduced and the life of equipment extended.

Station Arrangements

Percy L. Richardson, E. I. du Pont de Nemours & Co., discussed "What Industry Wants From the Electric Utility Industry." The author reviewed briefly the policy of the du Pont Company with respect to purchasing versus generating electric power. In view of the du Pont primary interest in the manufacture of chemicals, textiles, and numerous other products and not the generation of electric power, they prefer, with few exceptions, to purchase all of their electric requirements. They depend exclusively on purchased electric power in 63 out of a total of 75 manufacturing plants; in two of their plants they generate all of their own electric power. In the remaining ten plants they generate a portion of the power and purchase stand-by or supplementary service from the local utility company.

For a number of years the du Pont Co. has been obtaining its steam, electric, and water supply for two of its major chemical plants in New Jersey; namely, from the Deepwater Generating Station of the Atlantic City Electric Co. and in the second case from the Greenwich Generating Station of the same utility. They are not unique, however, in this respect as was seen from a partial list of installations the author gave of concerns that obtain steam and electric service from adjacent utility, under various types of contracts. It is suggested that electric utilities, when industrial districts are being promoted should investigate the possibilities of furnishing combination steam and electric services.

Mr. Richardson then recounts other possibilities: (1) use of older generating plants for furnishing of steam; (2) long range planning; (3) quality of electric service; (4) rate considerations in site studies.

Frank P. Hyer, Delaware Power & Light Co., presented a paper on "The Unique Delaware Power & Light—Tidewater Agreement." During recent years, the author recalled, several utility companies have made agreements with other industries to supply their steam and electrical requirements from power plants constructed adjacent to industrial sites. This has long been the practice of the Pacific and Gulf Coasts where the petroleum industry has contracts with utility companies for steam and electric power service. As a result of this trend Delaware Power & Light Company (DP&L) contracted with Tidewater Oil Company (TW) in 1955 to build and operate a power plant adjacent to TW's Delaware Flying "A" Refinery site to supply this refinery with steam and electricity. The contract also calls for operation and maintenance of the water-treatment plant which supplies both the refinery and the power plant. The water-treatment plant is owned by TW and leased to DP&L.

DP&L agreed to construct at its expense adjacent to TW's refinery (1) a steam-electric power plant, including necessary auxiliaries and a substation on land purchased from TW, and (2) a transmission line to connect the power plant with its transmission system: and upon completion of this construction, to operate and maintain the power plant to produce process steam and power which TW agreed to take.

Under terms of the agreement the power plant was designed to burn fuel oil, refinery gas, and fluid coke; but provisions were made in design for possible future use of bituminous coal. TW's initial requirements of power and process-steam dictated an installation of three boilers, each rated at 500,000 lb per hr, two turbo-generators, each having a nominal capacity of 25,000 kw, and necessary auxiliaries and a substation. Furthermore, the power plant was designed to permit extension of the buildings and the installation of such additional capacity as might be required by TW and arranged for by further agreement between DP&L and TW.

TW agreed to deliver at its expense all river water necessary to operate the power plant, and all raw fresh water including sanitary water to the water-treating plant required to supply steam and treated water.

TW agreed to sell to DP&L and DP&L agreed to purchase from TW bunker C or other satisfactory fuel oil, fluid coke, and/or refinery gas for the fuel requirements of the power plant at prices to be mutually agreed upon. DP&L agreed to burn all surplus refinery gas as made available by TW to the maximum extent required for boiler operation. Provision is made for purchase of fuel requirements from other sources under special circumstances at mutually agreed prices.

In the same vein the author summarized the other points of the agreement and discussed operations.

A new concept of the regenerative cycle utilizing a single variable as a criterion of the thermodynamic excellence of the feedwater-heating system for any given set of cycle boundary conditions was introduced by **J. K. Salisbury,** Consulting Engineer, in a paper entitled "A New Performance Criterion for Steam-Turbine Regenerative Cycles."

The variable, designated as H_e, is defined concisely as the flow-weighted enthalpy of extraction steam. It is, in effect, the "center of gravity" of the turbine extraction enthalpies. The author extols its simplicity as a concept, and the ease with which it may be determined in

an actual power plant, which he believes, enhance its usefulness. Mr. Salisbury expressed the thought that those who have worked with regenerative cycles have worked around the concept probably many times, without identifying it, or exploring its usefulness as a tool.

This paper presents an exposition of the H_r concept, but does not develop the ramifications of its use. A few of the quantitative relationships in approaching complete performance monitoring were advanced. This variable is responsive to any change whatsoever that may occur within the heater system, and moreover quantitatively indicates the net effect on the heat rate. Since it is an overall criterion, readily obtainable from relatively few data, it is believed that its applications are manifold in areas such as analysis of cycle designs, appraisal of the effect of changes, and monitoring of the performance of existing systems, for comparison with guarantees.

J. H. Potter, Stevens Institute of Technology, spoke on the subject, "The Utilization of Waste Heat." The basic consideration, Dean Potter believes, is that sound waste-heat utilization should be built around a continuous rather than a batch process, and it should contribute either to the process itself or to auxiliary operations. Gas, liquid, vapor, or solid may be used to absorb heat from a high-temperature source, then physically convey or transport this heat to a lower-temperature receiver.

Each waste-heat recovery scheme must be considered in terms of the processes involved, the cost of fuel, and the uses to which the heat or equivalent energy can be put. It is difficult to generalize on this subject, but certain features stand out which will serve to indicate a trend:

(1) Many years ago Gerbel found that only six out of 31 industries could balance process-steam requirements with power requirements. He took as his yardstick 6–16 times as much steam as horsepower-hours per unit of product. An excess of steam or of power was found in each of the remaining 25 industries.

(2) With the great improvements in central-station heat rates, purchased power has in most cases become more economical than that generated in industrial power plants. A large utility recently showed that purchased power would be cheaper than that obtained from process steam as a by-product in a 2000-kw turbine, and about the same as from a 5000-kw by-product operation.

(3) In terms of return on investment the industries can show more profit from operation of improved manufacturing or process equipment than from power-generating equipment.

(4) Power generation from the incineration of refuse has made no significant progress over the last decade, in spite of the fact that fuel was available at no cost.

(5) Elaborate waste-heat utilization systems involving thermal cascading or multiple-recovery cycles or very unusual apparatus will find less justification in the future. The costs of installing, operating, and maintaining such equipment will offset the potential savings.

(6) Important progress can be made in waste-heat utilization where the improvements can be made in the basic process. The metallic recuperators are examples of devices that have great process potential.

(7) West has suggested that waste heat should always be used for space heating, but cautions that unless the salvage plant can show a return of at least 10 per cent over and above carrying charges it is not attractive.

(8) The new vehicle types of heat-transfer equipment may have an important impact upon the process industries. It is probable, however, that they will be considered as part of basic processes rather than as heat-recovery devices.

(9) There are many areas where heat-recovery equipment is not justified but where improvements in the process could be effected by recirculation of part of the waste gases.

Fuel Cells

Research on the fuel cell has been carried out sporadically for almost a hundred years, but there has been a decided awakening of interest in recent years. Hence the paper, "Fuel Cells," by **Everett Gorin** and **Howard L. Recht,** Consolidation Coal Co., was a welcome one.

By definition, a fuel cell is a primary electrochemical device which effects the oxidation of a fuel with conversion of a substantial portion of the heat of combustion directly to electrical energy. A true fuel cell must operate continuously with a steady and constant output of electrical energy and with continuous supply of fuel to the negative electrode and of oxidant to the positive electrode. Only recently have fuel cells been devised which begin to meet this criterion of steady output.

The main attraction of the fuel cell is the potentially higher efficiency that can be achieved in the conversion of natural fuels to electrical energy. It does not, in itself, introduce a new source of energy such as in the case of nuclear fission and fusion. Its main function would be to extend our resources of fossil fuels.

A number of different types of fuel cells have been under development. All cells for which any success has been claimed operate with gaseous fuels, and discussion was limited to these. Ultimately, of course, the authors' company is interested in the use of solid fuels, particularly coal, which is by far our most abundant fossil fuel for generation of power. Prior gasification of coal can be used to produce fuel gas for use in the fuel cell. Further, this operation can be conducted in integration with the fuel-cell process itself to produce a high potential efficiency for generation of power from coal as well as from other natural fuels.

There are really two basic types of fuel cells that have been under development. The low and medium-temperature cells operate broadly in the temperature range of room temperature to about 250 C. These cells are characterized by the fact that high output is only achieved when relatively pure hydrogen is used as the fuel and pure oxygen as the oxidant.

The most highly developed cell of this type operates at moderately elevated temperatures and at relatively high pressures of about 600 psi. This is the cell developed by F. T. Bacon in England, whose use in this country is being developed by the Patterson Moos Division of the Universal Winding Co.

These hydrogen-oxygen cells have achieved considerable success in the course of their laboratory development. They are of interest for specialized military and possibly civilian applications. In their present state of development, however, they cannot be regarded seriously as a major power source.

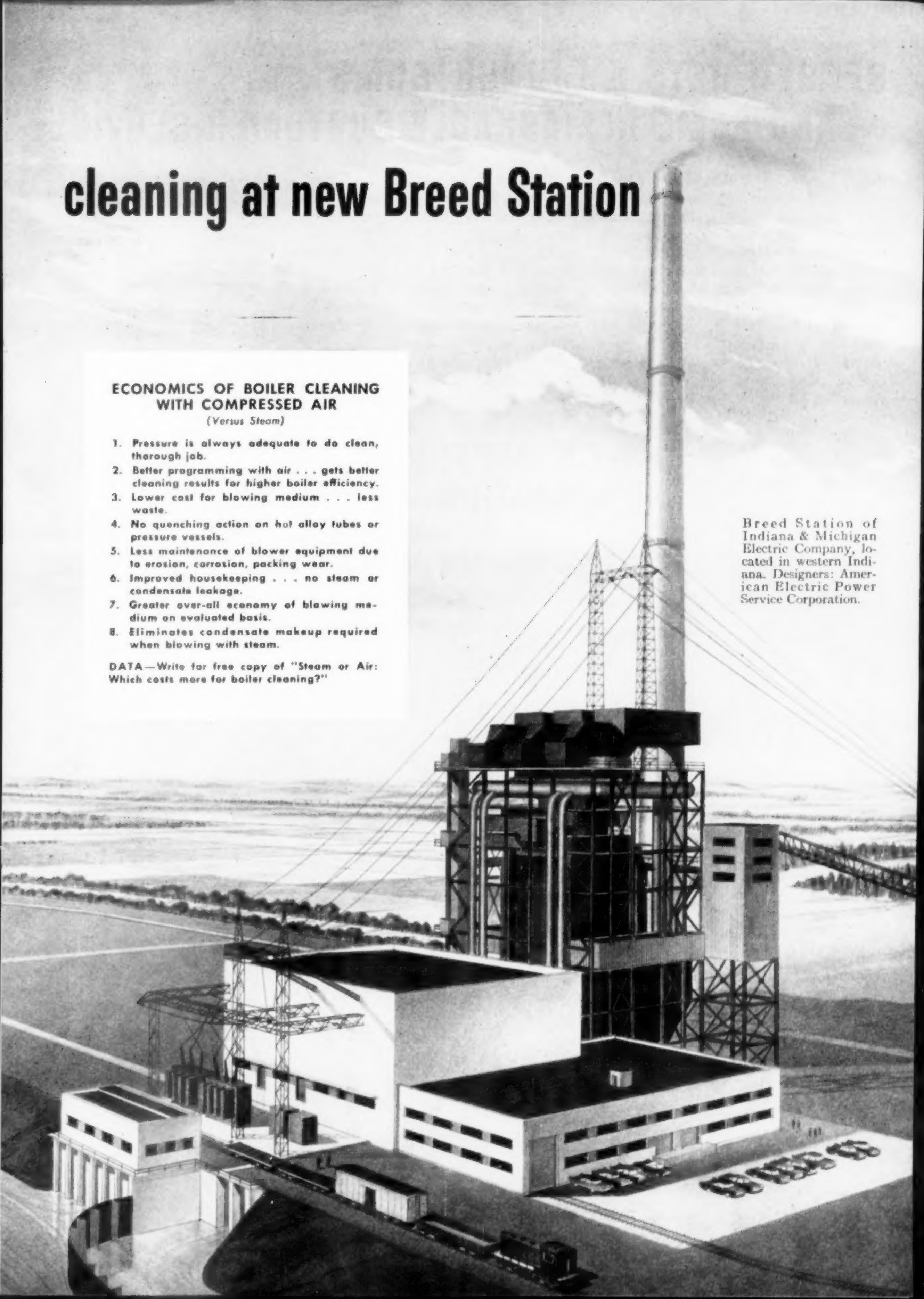
cleaning at new Breed Station

ECONOMICS OF BOILER CLEANING WITH COMPRESSED AIR

(Versus Steam)

1. Pressure is always adequate to do clean, thorough job.
2. Better programming with air . . . gets better cleaning results for higher boiler efficiency.
3. Lower cost for blowing medium . . . less waste.
4. No quenching action on hot alloy tubes or pressure vessels.
5. Less maintenance of blower equipment due to erosion, corrosion, packing wear.
6. Improved housekeeping . . . no steam or condensate leakage.
7. Greater over-all economy of blowing medium on evaluated basis.
8. Eliminates condensate makeup required when blowing with steam.

DATA—Write for free copy of "Steam or Air: Which costs more for boiler cleaning?"



Breed Station of Indiana & Michigan Electric Company, located in western Indiana. Designers: American Electric Power Service Corporation.

Abstracts From the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustions, Ltd., London, W. C. 1)

Fuels: Sources, Properties and Preparation

General Considerations on the Origin of Coals and Coal Fields. G. Stadnikoff. *Brennst Chemie* 1958, **39** (Aug.) 235–9 (In German).

Differences in the composition of coals can be explained by the differences in plant material from which they originate. Differences in rank can be explained by paleographical conditions at the time of the deposition of the plant material, without assuming increased temperatures and pressures. This also explains in which cases Hilt's law of increase of rank with depth is correct and why and where exceptions must be expected.

Pneumatic Handling of Bulk Materials. W. Farnworth. *Chem. Proc. Engng.* 1958, **39** (Sept.) 311–3.

The basic principles of vacuum, pressure, combined vacuum-pressure and fluidized pneumatic conveyor installations are set out and examples of application described.

Heat: Cycles and Transmission

Dropwise Condensation in Evaporators. D. E. Garrett. *Brit. Chem. Engng.* 1958, **3** (Sept.) 498–503.

Pilot-plant screening tests, single-plant heater tests and full-scale plant tests in which a large number of promoters of dropwise condensation were used proved entirely unsuccessful, as no continuous dropwise condensation could be obtained. The reasons for this failure are discussed.

Steam Generation and Power Production

Dimensionless Coefficients of Mixture Formation in Combustion Chambers. Part II. W. H. Fritsch. *Energie* 1958, **10** (Aug.) 317–23 (In German).

The theoretical study of the first part is continued, with a discussion of the time required for the mixing of the combustible content of the fuel and the air. This is based on Gumz's diffusion theory. The time constant of diffusion is deduced and graphs are presented, giving diffusion burning time of liquid and solid fuels as a function of volatile content and excess air. The influence of nonuniformity of fuel droplets or pulverized coal particles on burning time is considered and equations are derived for calculating the burning time of a particle mixture.

Calculation of the Entry Velocity of Water into the Risers of Natural Circulation Steam Generators. T. Schroeder. *Energie* 1958, **10** (Aug.) 322–31 (In German).

Equations are developed for calculating natural circulation in boilers, in which the riser tubes are nonuniformly heated over their length or bifurcated. The calculation takes into account changes of specific weight and velocity over the length of the riser tube. Since the various losses appear individually in the calculation, it is easy to see which design alterations have to be applied so that the entry velocity is sufficient to guarantee natural circulation. A numerical example explains the application of the equations.

Determining Moisture in Steam at High Pressures. A. V. Ratner and V. G. Zelenskii. *Teploenergetika* 1958, **5**, No. 5 (May) 44–6 (In Russian).

Results are given of an experimental study of the flow factors of Venturi tubes in water, steam/water mixture and steam. The tests show that the flow factors for a vertical flow-metering tube for rates of 1–3.5 *t/h* in cold and hot water, superheated and wet steam (steam content x = 0.065–0.65 at 160–170 atm abs pressure) are practically identical, equalling 0.99–1. Thus, with a knowledge of the consumption in sections where a single-phase liquid is flowing renders it possible to determine with the aid of the flowmeter the wetness of the steam.

From *C.E.G.B. Digest* 1958, **10** (Sept. 13) 2472.

An Investigation of the Variation in Heat Absorption in a Pulverised-coal-fired Slag-tap Steam Boiler at Blaine Island, Charleston, W. Va. A. A. Orning, M. Weintraub, C. H. Schwartz, E. A. Mihok, C. R. McCann and W. C. Harrold. *Trans. A.S.M.E.* 1958, **80** (Aug.) 1239–50.

The furnace heat absorption was determined from the furnace exit gas composition and temperature in 18 tests on a steam generator rated at 250 klb/hr of steam at 675 psi and 670 F. The furnace was fired with pulverized coal through opposed burners with reinjection of fly ash, over a refractory-insulated slagging bottom. Furnace heat absorption, at various load and excess air values, was correlated with the adiabatic flame temperature and the residence time of combustion products in the furnace. The furnace performance was found to depend upon burner adjustments, but did not significantly depend on recirculation of fly ash.

Natural Circulation Investigations on an Experimental Two Tube Boiler. A. M. Laird, A. W. Scott and A. S. T. Thomson. *Pap. to N.E. Cst Instn Engrs Shipb.*, **7** Mar. 1958, 30 pp.

The British Shipbuilding Research Association's experimental two tube water-tube boiler, built to investigate natural circulation phenomena and designed for a maximum pressure of 1500 psi, and a maximum heat input rate of 120,000 Btu/hr sq ft is described. In the boiler provision is made for varying tube diameter, length and inclination. After giving some details of the instrumentation, the paper describes the experimental results; all these relate to vertical tubes. The main series of experiments shows the influence of tube diameter, pressure and heat input rate on circulation velocities, and additional tests indicate the effects of restricting orifices in the circuit, nonuniform heating of the riser, shortening the heated length and rapid drop in boiler pressure. The following general results were obtained: under steady operation, natural circulation was more than adequate to deal with the maximum heat loading and evaporation rate attained in these tests; tube diameter had an important influence on circulation rate at all conditions within the range studied; for the $2^1/_4$, $1^3/_4$, and $1^1/_4$ in. tubes, the maximum circulation velocities attained were roughly 5, 4 and 3 fps; at pressures above 400 psi and heat input rates in excess of 40,000 Btu/hr sq ft, changes in pressure and heat input rate became relatively less important; nonuniformity of heating around the riser tube was unimportant; the rate of drop in pressure to produce circulation failure was related to boiler pressure and to the circulation velocity obtaining before pressure drop occurs. Difficulties arise in correlating results due to lack of information regarding the component factors affecting circuit resistance. Measurement of density and determination of flow pattern in the riser by the gamma ray technique,

described in the appendix, should provide much of this information.

From *Fuel Abstracts* 1958, **24** (Aug.) 1554.

High Pressure Steam Generator as SiO_2 Filter. R. Dolezal. *Mitt. V.G.B.* No. **55,** 1958 (Aug.) 289–96 (In German).

A theoretical study is presented of the distribution of SiO_2 in the boiler water and steam, the concentration of SiO_2 in the boiler water and means of reducing the SiO_2 content of the steam in boilers with natural circulation. By applying the previously described two-stage system of evaporation, the retention and concentration of the SiO_2 in the boiler water can be considerably increased because purer steam generated in the first stage does not come into contact with the highly concentrated boiler water of the second stage. In forced flow boilers operating at subcritical pressure, the salt removing vessel fulfills a similar rôle, but this is less efficient than two-stage evaporation. With a pressure approaching the critical pressure, the salt removal vessel becomes less efficient and above the critical pressure it is useless.

Operating Results of an Experimental Supercritical Steam Generator. E. Daman, H. Phillips, J. Vail and S. Ling. *A.S.M.E. Preprint* 58-SA-17, 1958 (June) 11 pp.

Results obtained on a 2000 lb/hr, 5500 psi and 1200 F supercritical pilot plant during 5000 hr of operation are presented. The main investigations were concerned with water treatment, operation of controls and stability of the circuit under sub- and supercritical pressure operating conditions.

Operation of a Once-through Boiler on Anthracite Duff with Liquid Slagging. S. G. Markin, V. P. Popov and V. E. Shtefan. *Elkt. Sta.* 1958, **29** (Apr.) 7–11 (In Russian).

A description and report of operation of the first model of the 67-2-SP-230/100 boiler, which is designed to run on pulverized anthracite and generate 230 tons/hr of steam at 100 atm and 510 C. Operation was satisfactory. The length of run is limited to 2500–3000 hr by the burning away of the tilting cones on the burners.

From *Fuel Abstracts* 1958, **24** (Aug.) 1567.

The CO Boiler of Standardised Design—Effective Answer to Economic Recovery of Refinery Waste Heat. T. J. Harvey and P. C. Trounce. *Combustion* 1958, **30** (Aug.) 34–9.

The waste gas from the regeneration of catalysts has a C.V. of 15 Btu/cu ft at a temperature of 1000 F and can, together with fuel oil, be used to generate steam in a boiler. In a C.E. boiler rated at 100 klb/hr at 250 psi, a saving of 68 mill. Btu/hr is obtained by the use of this waste gas. The boiler is of the conventional water tube design with pressurized furnace and tangential firing. Operating experience with the boiler has been excellent; it has averaged 8000 hr/year and was shut down only when the regeneration unit was also shut down for maintenance. Maintenance cost was very low.

Cooling Tube System Protects Bare Refractories in the Burner Corners of a Slag-tap Furnace. M. Schulz. *Energie* 1958, **10** (Aug.) 335–7 (In German).

The refractory bricks in the corners of boiler fired with pulverized coal and blast furnace gas were rapidly destroyed by the high furnace temperature, as the riser tubes could not provide adequate cooling. Since it was impossible to space the riser tubes more closely, it was decided to install a system of cooling tubes between the riser tubes and the burner mouth fed by boiler feedwater. Care had to be taken to ensure sufficient water velocity to avoid evaporation of the feedwater. After the installation of these cooling tubes, the refractory tubes have now lasted for over 20,000 hr with only minor damage.

Single Stage Copper Removal Treatments Lengthen Boiler Tube Life. J. P. Engle and R. W. Fitzgerald. *Pwr. Engng.* 1958, **62** (Aug.) 76–8.

Dow Chemical Co. has developed a complexing agent, to be added to the acid cleaning solution, which prevents the copper precipitating out of the solution again and adhering to the tube wall. The agent can be used only where iron deposits are also present; if the copper deposit is very heavy, a preliminary treatment with acid without the agent is recommended to reduce the cost of the treatment.

Liquid and Gaseous Fuel Firing

Oil-firing for Steam Generators. O. Rosahl. *Techn. Mitt.* 1958, **51** (July) 326–36 (In German).

Developments in oil-firing techniques, since the author's lecture in 1956 (see abstract No. 1807, 1957), are described. Examples are given of installations in many different countries, and the experience obtained is discussed. Particular reference is made to heat release rates in the furnace, replacing of pulverized coal by oil and combined firing, low temperature corrosion and additives, high temperature corrosion and an economic comparison between oil and coal firing.

Oil Burner Systems and Their Tasks with Regard to Combustion and Heat Transfer. W. Hansen. *Techn. Mitt.* 1958, **51** (July) 286–94 (In German).

Various designs of atomizing, vaporizing and gasifying burners, their principles of operation, advantages and disadvantages are described.

Burner Maintenance. R. D. Reed. *A.S.M.E. Preprint* 58-SA-56, 1958 (June) 7 pp.

The various factors making burner maintenance necessary, such as the corrosive nature of the gas or oil, the temperature in the furnace, dissociation or polymerization of the gas, solid matter entrained in the gas or oil are considered and advice is given on restoring the individual burner parts to their original state.

Furnaces and Combustion

Experiments with a Vortex Furnace. T. R. Cave-Browne-Cave. *Engr.* 1958, **206** (Aug. 22) 292–3.

Coal firing trials on an experimental vertical cyclone furnace are reported, during which heat release rates of 240,000 Btu/cu ft and hr were obtained. From the results of the trials,

the dimensions of a cyclone furnace are deduced which would give optimum combustion conditions.

Use of Flux with Coals with High Melting Point Ash in the Cyclone Method of Combustion. I. Ya. Zalkind, T. V. Solomatina and M. A. Nadzharov. *Teploenergetika* 1958 (Apr.) 34–41 (In Russian).

The effect of the mineralogical composition of the ash and slag of coals on their apparent viscosity is examined. Data are given on the reaction of different fluxes with slags. It is shown that the range of fluxes that can be used in cyclone furnaces is extended if fluxes are added in amounts equivalent to up to 25% by weight of the ash.

From *Fuel Abstracts* 1958, **24** (Aug.) 1584.

Flue Gas, Ash and Dust

Experiments on an Industrial Venturi Scrubber. J. A. Brink and C. E. Contant. *Ind. Engng. Chem.* 1958, **50** (Aug.) 1157–60.

The collection efficiency and pressure drop of a Venturi scrubber were investigated. It was found that the efficiency depends on the aerosol size and that larger particles are removed at a higher efficiency than smaller ones. For particles of 1 μ diam the collection efficiency was 98%, for those of 0.5 μ diam only 78%.

Progress Review No. 45: Handling, Disposal and Utilisation of Ash from Power Stations of the C.E.G.B. S. H. Dawson. *J. Inst. Fuel* 1958, **31** (Sept.) 401–5.

Hydraulic and pneumatic systems of furnace hopper and fly ash disposal and a number of improvements introduced recently are described. Schemes of fly ash utilization for producing light weight aggregate, bricks and concrete, and for road construction and filling material at building sites are outlined.

Process of Producing Constructional Material from Flue Dust. Metallgesellschaft A.G. *British Patent* 800,-913 Germany, 8th July, 1955.

The flue dust is formed into pellets and then sintered. Either pellets of 1–4 μ diam are formed, with addition of coke, and then sintered on a grate to form a cake which is broken up to sizes below 20 mm and can be used as concrete aggregate; or pellets of 8–12 μ diam are formed, rolled in fuel and sintered as individual pellets for use as constructional material.

Air Coolers and Air Condensers in Local Power Stations. C. Peschon. *Energie* 1958, **10** (Aug.) 331–3 (In German).

Various installations of air condensers for small power stations at the Luxembourg iron and steel works are described, which have been sited either on the ground or on top of workshops where other space was not available. Experience has shown that elliptical tubes with or without fins are preferable to round tubes, as the pressure loss is smaller and there are less dead zones.

Experience with Austenitic High Temperature Spray Desuperheaters in a 600°C Industrial Power Station. F. Wehrberger. *Mitt. V.G.B.* No. 55, 1958 (Aug.) 268–74 (In German).

The failure, due to cracking of the austenitic spray desuperheater in the new Hüls power plant, is described and the causes (thermal shock) discussed. The new design evolved to avoid crack formation is illustrated.

Power Generation and Power Plant

Power Plant Criterion. T. Baumeister. *Elect. World* 1958, **150** (Aug. 25) 72.

It is argued that a true comparison between gas, oil and coal-fired power stations can only be obtained if the thermal efficiency or heat rate is based on the net C.V. and not on the gross C.V. as at present done in America.

The Uranium-graphite Reactor and Superheated Steam Power Stations. N. A. Dollezhal. *J. Nuc. Eny* 1958, **7** (Aug.) 109–14.

Expressions are given for assessing the economy of nuclear power stations; these indicate the large number of different technical approaches which are possible and their study forms one of the most complicated regions of modern technology. A description is given of a high temperature steam-generating reactor which will be used in one of the nuclear power stations under construction in the USSR. The reactor is designed to produce 100 MW(e) with a standard steam-turbine set; steam is generated in the boiler at 110 atm and superheated to 510 C directly in the reactor, giving an efficiency of 35–38%.

From *C.E.G.B. Digest* 1958, **10** (Sept. 13) 2501.

Materials and Manufacturing Processes

Use of 1 Cr 18 Ni 12 Ti and EI-724 Steels for Tubes of Boiler Installations with Extra High Parameters. G. P. Fedortsov-Lutikov and T. S. Griboedova. *Energomashinostroenie* 1958, **4** (May) 28–34 (In Russian).

The results are set out, with various charts and tables, of a study of the properties of austenitic chromium-nickel steel types 1 Cr 18 Ni 12 Ti, 1 Cr 18 Ni 9 Ti and EI-724. They show, *interalia*, that in mechanical properties and durability these steels satisfy the requirements of boiler steels for steam parameters $p \leq 230$ atm gage and $t = 600$–610 C.

From *C.E.G.B. Digest* 1958, **10** (Sept. 27) 2623.

The Application of Austenitic Steels in the New Hüls Power Station. A. Engl. *Mitt. V.G.B.* No. **55**, 1958 (Aug.) 255–64 (In German).

Details are given of the composition, mechanical properties and dimensions of the steels used, their application in the boiler, superheater and reheater, and the topping and condensing turbine, their welding, and of various tube failures.

New Welding Processes. C. W. J. Vernon. *Weld. Met. Fabric.* 1958, **26** (Sept.) 328–37.

A review of developments during the past two years, including new CO_2

techniques, dual gas shielding, ultrasonics, bonded fluxes, electron-beam fusion, automatic pipe joining and high-frequency resistance welding.

Post-weld Treatment of Welded Units for the Relief of Stress. S. J. Watson. *Weld. Met. Fabric.* 1958, **26** (Sept.) 318–22.

The reasons for applying stress-relief treatment, methods available (heat, plastic straining) and testing of stress relief are discussed.

Instruments and Controls

Computor Reduces Man-hours in Fuel Analysis Calculations. C. J. Wegert and W. H. Guppy. *A.S.M.E. Preprint* 58-SA-62, 1958 (June) 8 pp.

The IBM 705 computer has been used to calculate and produce a complete fuel analysis and consumption report for the Commonwealth Edison Co. every month. The procedure is described and the costs analyzed. It is shown that the use of the computer is economic for simple repetitive calculations.

Nuclear Energy

Peaceful Uses of Atomic Energy. Anon. *Engineer* 1958, **206** (Sept. 5) 380–2.

Abstracts are given of the Presidential address by Professor F. Perrin to the 2nd International Conference of the United Nations on the peaceful uses of atomic energy, in which the application in highly industrialized and underdeveloped countries, the harmful effect of secrecy, the prospects of thermonuclear fusion, the continued importance of the fission process, the dangers of ionizing radiation and difficulties of waste disposal were reviewed.

Summary of the Geneva Conference. Sir John Cockroft. *Engineering* 1958, **186** (Sept. 19) 372–5.

A broad survey of the new knowledge disclosed in the papers presented to the Conference.

Atomic Review. World Programme. Anon. *Engineering* 1958, **186** (Aug. 29) 262–5.

The major national and international atomic energy programmes of Great Britain, U.S.A., U.S.S.R., France, Canada, India, Australia and South Africa and of the International Atomic Energy Agency, European Nuclear Energy Agency (O.E.E.C.), Euratom, Cern and Joint Nuclear Research Institute are outlined.

U.S. Exhibits Reactor with Unique Fuel-Moderator. Anon. *Nucleonics* 1958, **16** (Aug.) 116.

The training, research and isotope production reactor (TRIGA) designed

by General Atomic has been exhibited at the Geneva Conference because of the special feature of the reactor's inherent safety. This is obtained by the core, which has a negative temperature coefficient, due to the fuel elements containing a homogeneous blend of uranium and zirconium hydride clad in aluminium. Details of the power, core tank, core, control rods, fuel elements, moderator and coolant are given.

Heat Extraction in Power Reactors. 4. G. Boxer. *Nucl. Pwr* 1958, **3** (Sept.) 439–43.

Estimation of pressure drop in the primary coolant, due to friction and change of density, and the criteria governing the choice of a suitable primary coolant are discussed.

Reactor Test Loops. 4. Obtaining the Results. D. T. Norsworthy. *Nucl. Pwr* 1958, **3** (Sept.) 431–4.

The purposes for which the loops are used and the type of information to be obtained are described. The problems investigated include: (1) Coolant technology; (2) Coolant stability; (3) Fuel element testing; (4) Heat transfer data; (5) Fission product behavior.

U. S. Designs Gas-cooled Reactors. Anon. *Nucleonics* 1958, **16** (Aug.) 118–21.

American studies of the gas-cooled reactor indicate that it would be possible to build a reactor more advanced than Hinkley Point, mainly by increase of coolant gas pressure and outlet temperature. Welding of thicker pressure vessels and overcoming distortion of fuel elements at higher temperatures by their rotation are discussed. It is estimated that a slightly enriched design would produce cheaper power than natural uranium designs.

Uranium. 1. The Case for Enriched Uranium. C. Starr. *Nucleonics* 1958, **16** (Aug.) 86–7.

The use of enriched uranium is recommended because of the lower capital cost of the reactors and, consequently, of the power produced. Figures are quoted to support this contention.

Uranium. 2. The Case for Natural Uranium. J. R. Menke. *Nucleonics* 1958, **16** (Aug.) 88, 95.

Natural uranium appears to be an economical proposition for the heavy water moderated reactor, though not for the graphite moderated reactor, and would lead to a more effective utilization of the fuel, especially if recyling is considered.

A.E.C.'s Fuel Programme. R. C. Dalzell, W. K. Davis, C. Goodman

and U. M. Staebler. *Nucleonics* 1958, **16** (Aug.) 78–81.

The program of the A.E.C. in developing more efficient fuels for reactors, using U233, U235, U238 and Pu, is outlined. This embraces: (1) Research into fissionable, fertile and structural materials, to reduce costs; (2) Fuel elements with increased resistance to irradiation and longer life at high temperatures; (3) Full or partial core loading of prototype fuel elements for testing under normal reactor operating conditions.

Grinding, Screening and Filtering

The Performance of an Air-swept Tube Mill. F. J. Hiorns and L. E. Reed. *J. Inst. Fuel* 1958, **31** (Sept.) 383–92.

Tests carried out on a full-scale air swept tube mill without classifier, using two coals with Hardgrove indices of 51 and 64, respectively, have shown that under normal operating conditions the fineness of the product fell and output rose linearly as the air rate through the mill was increased. This relationship ceased to hold if the heat available was insufficient to dry the coal. Neither ball charge, nor coal level in the mill affected output, but increased ball charge increased the power consumption of the mill.

From authors' abstract.

Analysis and Testing, Research

Methods of Testing Automatic Coal Samplers. A. W. Davis, D. A. Hall and R. C. Tomlinson. *J. Inst. Fuel* 1958, **31** (Sept.) 406–13.

A guide for testing automatic coal samplers is presented and the principles on which the tests should be based are stated. Three methods for providing a standard of reference are described and results of tests on a belt sampler presented. Causes of bias shown by all automatic samplers investigated are discussed. Where the product to be sampled is liable to great variation, trials with artificial mixtures are required.

Simple Way to Measure Steam Quality. R. Lemlich. *Chem. Engng.* 1958, **65** (Apr. 7) 162.

A simple calorimeter for determining the temperature, and hence the enthalpy and moisture content of steam, is described. It consists of a short length of tubing for sampling the steam, leading through a needle valve and a notched two-hole stopper to an inverted 1 pint thermos bottle. Steam is allowed to pass through the valve, into the thermos and when issuing freely the temperature can be read by means of a thermometer which passes through the stopper.

From *Fuel Abstracts* 1958, **24** (Aug.) 1547.

Advertisers' Index

Aerotec Corporation, The..... *
Air Preheater Corporation, The 58
Alco Products, Inc............ *
American-Standard, American Blower Division............ *

Bailey Meter Company........ 17
Ballard, Sprague & Thomas, Inc........................ *
Baltimore & Ohio Railroad.... *
Bayer Company, The.......... 2
Betz Laboratories, Inc......... *
Bird-Archer Company......... *
Bituminous Coal Institute.... *
Blaw-Knox Co., Blaw-Knox Equipment Div.............. *
Brown Company.............. *
Buell Engineering Company, Inc........................ 26
Buffalo Forge Company....... 7

Cambridge Instrument Company........................ 41
Champion Rivet Co., The..... 67
Clarage Fan Company......... 68
Cochrane Corporation......... *
Combustion Engineering, Inc. ....Second Cover, 22 and 23
Combustion Publishing Co., Inc........................ *
Cooper-Bessemer.........56 and 57
Copes-Vulcan Div., Blaw-Knox Company................8 and 9
Crane Company.............. 21
Croll-Reynolds Engineering Co., Inc..................... *
Curtiss-Wright Corporation, Metals Processing Div....... *

Dampney Company, The...... 20
Dearborn Chemical Company. *
De Laval Steam Turbine Company........................ *
Diamond Power Specialty Corporation............Third Cover
Dowell........................ *
E. I. du Pont de Nemours & Co., Grasselli Chemicals Dept........................ *

Eastern Gas & Fuel Associates. *
Edward Valves, Inc.......10 and 11
Engineer Co., The............ *

Fairmount Chemical Co., The. 62

Graver Water Conditioning Company.................. *
Green Fuel Economizer Co.... 25

Hagan Chemicals & Controls, Inc....................13 and 15
Hall Laboratories, Div. of Hagan Chemicals & Controls, Inc.................... 3

(Continued on page 67)

Ingersoll-Rand Company...... *

Johns-Manville............... *

M. W. Kellogg Company, The. 24
Koppers Company, The....... 16

Ladish Co................18 and 19
Leeds & Northrup Company.. 42

Manning, Maxwell & Moore, Inc......................... *
Maryland Shipbuilding & Drydock Company.............. *
W. K. Mitchell & Company... *

National Aluminate Corporation....................6 and 66

Peabody Engineering Corporation......................... *
Pennsylvania Crusher Div., Bath Iron Works Corp....... 14
Pittsburgh Piping & Equipment Company............. *
Powell Valves.................. 38
Henry Pratt Company......... *

Refractory & Insulation Corporation..................... 64
Reliance Gauge Column Company, The.................. 63
Republic Flow Meters Company....................... *
Republic Steel Corporation.... *
Research-Cottrell, Inc......... *
Richardson Scale Company... 5
Rohm & Haas Company...... *

Standard Tube Co., The and Michigan Steel Tube Products Division................ 61
Stock Equipment Company... 48
Sy-Co Corporation............ 62

W. A. Taylor and Company... *
Todd Shipyards Corp., Products Div..................... *

Unafrax Construction Co...... 60

Valley Camp Coal Co.......... 12

Walworth Company........... *
Western Precipitation Corporation..............Fourth Cover
Westinghouse Electric Corporation....................... *
Westinghouse Electric Corporation, Sturtevant Div....... *
Worthington Corporation..... *

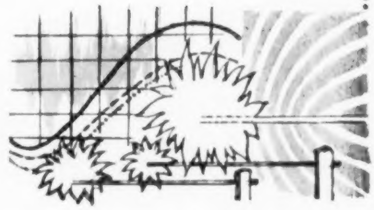
Yarnall-Waring Company..... 5
Yuba Consolidated Industries, Yuba Heat Transfer Div..... 4

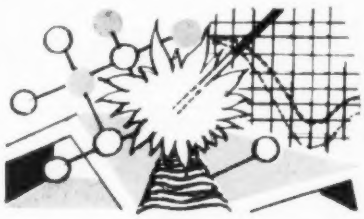
CRACKING Problems with 316 and 347 Stainless?

CHAMPION'S

16-8-2 Electrodes Offer freedom from CRACKING

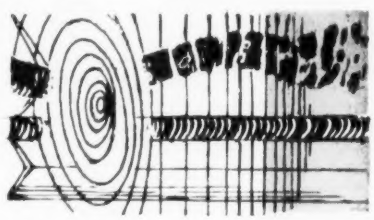
HERE'S WHY: New CHAMPION 16-8-2 Stainless Electrodes have a composition which has much higher hot ductility than any other grade of stainless. Produces freedom from cracking in weld, zone of fusion, or parent metal.





HERE'S WHY: Lime type coating deposits extremely clean, sound weld metal. Handles well in all positions. Low spatter. Easy slag removal. Smooth, even and finely rippled weld bead.

HERE'S WHY: Tests reveal that this composition is not subject to embrittlement on aging, and possesses very good stress-to-rupture properties.



Excellent mechanical properties are accomplished with CHAMPION 16-8-2 Welding Electrodes:

Yield	61,000 psi
Tensile	92,000 psi
Elongation in 2"	50%
Reduction of area	61.8%

The chemistry is closely controlled to produce less than 4% ferrite in the deposit.

Typical chemical analysis is as follows:

Carbon .08	Chromium 16.19
Manganese 2.24	Nickel 8.00
Silicon .37	Molybdenum 1.79

Other stainless requirements: CHAMPION offers a complete line of stainless electrodes in a full diameter range from 5/64" to 1/4", lime or AC-DC coated.

FOR FULL DETAILS on CHAMPION'S 16-8-2 or other stainless electrodes write to:

The CHAMPION Rivet Co.

Cleveland 5, Ohio • East Chicago, Indiana

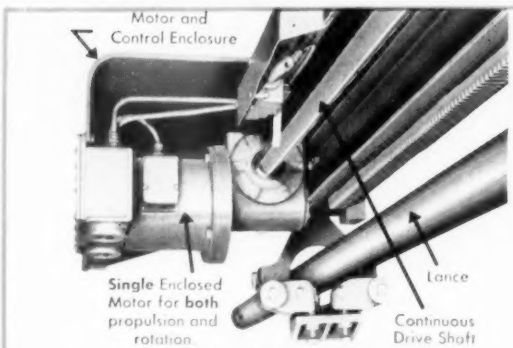
Reasons for the ENTHUSIASTIC ACCEPTANCE of the DIAMOND SERIES 300 IK

LONG RETRACTING BLOWER

Setting new and higher standards of efficiency, economy and dependability in the cleaning of heating surfaces that require a long retracting lance, the Diamond Series 300 IK Blower offers many outstanding features. Some of these are shown below. Others are: positive gear carriage drive . . . oversize lance (step-tapered for extra long travel) . . . designed for quick, easy servicing.

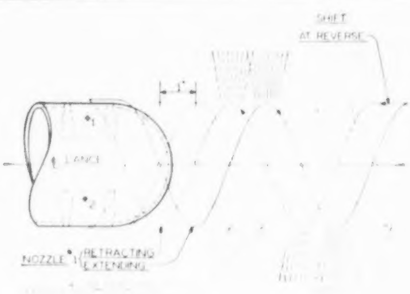
This new blower is the culmination of more than 20 years experience building and applying long travel blowers. It well illustrates the Diamond design philosophy: "Keep it simple . . . keep it basic . . . avoid unnecessary complications." It is further evidence of the fact that YOU CLEAN BOILERS BETTER AND AT LOWER COST WITH DIAMOND BLOWERS.

Ask your local Diamond office or write directly to Lancaster for Bulletin 2111.



STATIONARY GEAR MOTOR

Lance propulsion and rotation are by a *single* enclosed gear motor which drives a continuous shaft running the full length of blower and providing power to carriage. This construction makes it possible to mount motor in a fixed position at the front end for better protection and accessibility.



IMPROVED CLEANING PATTERN

Close and positively controlled helical cleaning pattern assures maximum cleaning effectiveness. Blowing pattern diagram illustrates how return travel path is exactly intermediate with forward travel path so that there is a positive nozzle sweep every inch.

Diamond

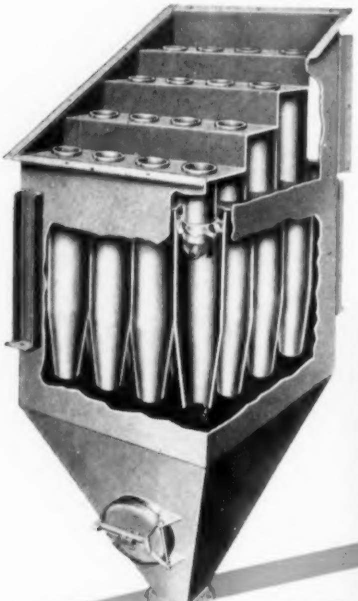
DIAMOND POWER SPECIALTY CORP.

LANCASTER, OHIO

DIAMOND SPECIALTY LIMITED—Windsor, Ontario

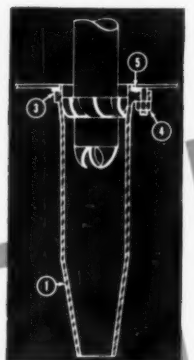
8089

13 BIG REASONS WHY MULTICLONE DUST COLLECTORS



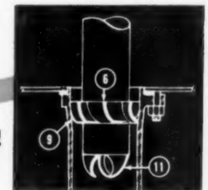
COST LESS TO MAINTAIN... ARE FAR SIMPLER TO SERVICE!

When you buy dust collection equipment, don't stop with a comparison of *initial* cost only. Compare also the costs and simplicity of keeping your dust collector at top-notch efficiency *throughout the years.* To the outstanding advantages of Multiclone's unique operating features, add the low cost and easy maintenance of this equipment and you'll see why Multiclones are the leading choice wherever *centrifugal* types of dust collectors are the most practical solution.



EASILY INSTALLED COLLECTING TUBES

1. **CAST IRON TUBES** assure long wear!
2. **SPECIAL ALLOY TUBES** (FBA Inco #40, Chromehard and Ni-Hard) can be supplied where high temperatures or severe erosion are problems!
3. **TUBES ARE PRECISION-CAST** for exact fit into tube sheet. Tube lip protects sealing gasket!
4. **TIGHT LEAKPROOF FIT** of each tube is maintained indefinitely by special lock nuts!
5. **GAS-TIGHT JOINT** between tube sheet and each tube is assured by special gasket. Joint can be easily renewed when replacing tube!



PRECISION CAST VANES!

6. **CAST IRON VANES** resist erosion!
7. **SPECIAL ALLOY VANES** (FBA Inco #40, Chromehard and Ni-Hard) can be supplied where high temperatures or severe erosion are problems!
8. **VANES ARE EASILY INSTALLED** by simply dropping new ones into place when changing collecting tubes!
9. **EXACT FIT OF EACH VANE** in the tapered collecting tube prevents erosive "blow-by"!
10. **CAPACITY AND EFFICIENCY** of the unit can be quickly altered by simply changing vanes. Assures easy adaptability to new operating requirements—big savings in plant modernization programs!
11. **SPIROVANES** (energy recovery devices) may easily be added to outlet tubes of existing installations to increase capacity or reduce pressure drop!

Plus These Important Advantages...

12. **CUBIC SHAPE** of Multiclone is easier to install and insulate — and requires only ONE simple inlet and outlet duct!
13. **BACKED BY OVER 3300 INSTALLATIONS** serving a wide cross-section of industry, each Multiclone benefits from the unequalled "know-how" gained during **Western Precipitation's half-century of leadership in the highly-technical field of modern dust collection!**

Compare the above advantages with any competitive equipment and you'll readily see why Multiclones are the logical choice for *your particular* operations, too. There's a Multiclone representative near you who will gladly supply further details to fit your individual requirements. No obligation, of course!

Send for descriptive literature on Multiclone equipment.